Proceedings of ROADS AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 9-11 September 1987

— Highway Operations

— Concrete and Structures
Proceedings of ROADS AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 9-11 September 1987

— Highway Operations
— Concrete and Structures
PREFACE

The Swedish Road and Traffic Research Institute (VTI) and the US Transportation Research Board (TRB) of the National Research Council were jointly organising this international conference. The objective was to cover the present and future road research with special emphasis on the Strategic Highway Research Program (SHRP), as well as the research concerning drivers and vehicles as related to highway safety.

Under development for 2-3 years, SHRP is a fully funded, $150 million (US), five year program of research directed at asphalt, concrete and structures, highway operations, and long term pavement performance.

In the different road safety sessions there were presentations of actual research in different countries and discussions of the differences that exist between Europe and the USA, trying to explain the reasons for them and examine whether they are reasonable and acceptable.

In the sessions of roads, the emphasis on the Strategic Highway Research Program (SHRP) was intended. Presentations did highlight differences between European and US practices and needs, and the discussions was concentrated on how to promote international involvement in SHRP and application of its research.

Linköping January 1988

Kenneth Asp

Proceedings of ROADS AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 9-11 September 1987:

VTI RAPPORT 328 A
- Opening
- Traffic Safety - Open Session
- Traffic Safety - General

VTI RAPPORT 329 A
- Long Term Pavement Performance
- Asphalt

VTI RAPPORT 330 A
- Highway Operations
- Concrete and Structures

VTI RAPPORT 331 A
- Driver Behaviour and Licensing
- Alcohol and Drugs
- Driving and Elderly

VTI RAPPORT 332 A
- Speed
- Vehicle Performance
- Crashworthiness
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>I</td>
</tr>
<tr>
<td>PROGRAM</td>
<td>II</td>
</tr>
<tr>
<td>HIGHWAY OPERATIONS</td>
<td></td>
</tr>
<tr>
<td>MAINTENANCE COST EFFECTIVENESS STUDIES FOR THE STRATEGIC HIGHWAY RESEARCH PROGRAM</td>
<td>1</td>
</tr>
<tr>
<td>Mr A D Andreas, Dep secretary of Transportation, Washington, USA</td>
<td></td>
</tr>
<tr>
<td>SHRP SNOW AND ICE CONTROL</td>
<td>17</td>
</tr>
<tr>
<td>Mr L David Minsk, Research Physical Scientist, US Army, CRREL, USA</td>
<td></td>
</tr>
<tr>
<td>ACTIVITIES IN FRANCE DESIGNED TO IMPROVE THE EFFICIENCY OF MAINTENANCE TECHNIQUES</td>
<td>28</td>
</tr>
<tr>
<td>Dr Jacques Bonnot, LCPC, F Verhee, SETRA and P Bense, LRPC, M Le Duff, LCPC, France</td>
<td></td>
</tr>
<tr>
<td>DEVELOPMENT OF MAINTENANCE MANAGEMENT AND CONTROL SYSTEMS</td>
<td>50</td>
</tr>
<tr>
<td>Dr Lars Bergfalk, National Road Administration, Sweden</td>
<td></td>
</tr>
<tr>
<td>&quot;HIGHWAY SNOW AND ICE CONTROL - NORDIC OVERVIEW&quot;</td>
<td>65</td>
</tr>
<tr>
<td>Mr Kent Gustafson, Chief Researcher, VTI, Sweden</td>
<td></td>
</tr>
<tr>
<td>CONCRETE AND STRUCTURES</td>
<td></td>
</tr>
<tr>
<td>STRATEGIC HIGHWAY RESEARCH PROGRAM - CONCRETE AND STRUCTURES</td>
<td>82</td>
</tr>
<tr>
<td>Mr L D Minsk &amp; Mr I Jawed, US Army, CRREL, USA</td>
<td></td>
</tr>
</tbody>
</table>

VTI RAPPORT 330 A
DEVELOPMENT IN THE NETHERLANDS IN THE FIELD OF CONCRETE AND STRUCTURES AND CONCRETE BLOCKPAVING
Dr Jan J M van der Vring, The Netherlands Centre for Research and Contract Standardization in Civil and Traffic Engineering, The Netherlands

DURABILITY OF ROAD AND BRIDGE STRUCTURES OF CONCRETE - NORDIC EXPERIENCES
Dr Bo Göran Hellers, Swedish Cement and Concrete Research Institute, Sweden

NORWEIGAN PRACTICE FOR CONCRETE BRIDGE DECK PROTECTION
Dr Erling K Hansen and Dr John E Haga, Norwegian Road Research Laboratory, Norway

THE USE OF 2 METRE SQUARE PRECAST CONCRETE RAFTS AS TEMPORARY; REUSABLE AND COST-EFFECTIVE ROADS
Dr John W Bull, University of Newcastle upon Tyne, United Kingdom
ABSTRACT

The papers presented at the seminar were as follows: Maintenance Cost Effectiveness Studies for the Strategic Highway Research Program (Andreas, A); SHRP Snow and Ice Control (Minsk, LD); Activities in France designed to improve the Efficiency of Maintenance Techniques (Bonnot, J, Verhee, F, Bense, P and Le Duff, M); Development of Maintenance Management and Control Systems (Bergfalk, L); Highway Snow and Ice Control. Nordic Overview (Gustafson, K); Strategic Highway Research Program. Concrete and Structures (Minsk, LD and Jawed, I); Development in the Netherlands in the field of Concrete and Structures and Concrete Blockpaving (van der Vring, J); Durability of Road and Bridge Structures of Concrete. Nordic Experiences (Hellers, BG); Norwegian Practice for Concrete Bridge Deck Protection (Hansen, E and Haga, J); The Use of 2 metre square Precast Concrete Rafts as Temporary; Reusable and Cost-Effective Roads (Bull, J).
### WEDNESDAY SEPTEMBER 9

**9.30**

**OPENING**

- **Roads and Traffic Safety**
  - Mr John Tabb, President of AASHTO, USA
  - Mr John Tabbbb, President of AASHTO, USA

- **Safety and SHRP from the Viewpoint of the States**
  - Mr John Tabb, President of AASHTO, USA

**Objectives of the conference**

- Mr K.B. Johns, Director, Transportation Research Board, (TRB), USA
- Mr Hans Sandebring, Director General, The Swedish Road and Traffic Research Institute (VTI), Sweden

**11.15**

**European Trends in Road Safety and Road Safety Research**

- Professor N O Jargensen, Technical University, Denmark

**11.45**

**Traffic Safety Research in the FHWA and the United States**

- Mr David Phillips, Associate Administrator, R & D Technology, Federal Highway Administration, USA

**PROMETHEUS — The European Automotive Industry Research Project**

- Dr Tage Karlsson, AB Volvo, Sweden

**12.30**

**LUNCH**

**14.00—17.00**

**TRAFFIC SAFETY — GENERAL**

- **Chairman**: Dir David Phillips, Federal Highway Administration, USA

  **The OECD Road Transport Research Programme**
  - Director General Hans Sandebring, VTI, and Chairman of the OECD Road Transport Research Programme

  **Traffic Safety Research Policy in the United States**
  - Dir K.B. Johns, Transportation Research Board (TRB), USA

  **R & D Policy in France in the field of Road Safety**
  - Director General G Dobias, Institut National de Recherche sur les Transports et leur Sécurité (INRETS), France

  **Road Safety Research in the Federal Republic of Germany**
  - Prof Dr H Praxenthaler, Head of Bundesanstalt für Strassenwesen (BASTI), the Federal Republic of Germany

  **Road Safety Research — Possible European Cooperation**
  - Dr A Hitchcook, Head of Safety and Transportation Group, Transport and Road Research Laboratory (TRRL), U.K.

  **Discussion on how to improve the cooperation between Europe and the United States within the field of traffic safety research.**

**14.00—17.00**

**Chairman**: Prof Kare Rumar, The Swedish Road and Traffic Research Institute

**A Method for Studying the Effect of Visual Field Defects, which could be a Tool when formulating Standards for Visual Fields**

- Dr Per Lovsund, Dep of traffic safety, Chalmers technology, Sweden

**Crash Avoidance Models**

- Dr Wade Allen, Principal Research Engineer, Systems Technology Inc, USA

**Driver Risk Perception in Spain and the USA**

- Dr Michael Sivak, University of Michigan, USA

**Theoretical Requirements for Drivers License in Austria**

- Dr Ch. Michalik, Kuratorium für Verkehrsicherheit, Wien

**Why can we expect New Scandinavian Driver Education Programmes to set International Standards and improve Future Skills of New Drivers?**

- Dr Birger Nygaard, VTI, Sweden

**Discussion**
### Thursday September 10

#### Asphalt

**8.30—12.00**  
Chairman: Mr Francis Francois, Executive Director of AASHO, USA  
Asphalt Characteristics Portion of SHRP  
Mr Joseph L. Goodrich, senior Research Chemist, Chevron Co, USA  
Asphalt Characteristics Portion of SHRP  
Dr Thomas Larson, Penn State University, USA  
French research on the methods of characterization of asphalt, polymer modified binders, asphalt mixes  
Dr J Bonnot, Laboratoire central des ponts et chaussées, France  
Bituminous Binders  
— Nordic Overview  
Dr Olav E Ruud, Norway  
Dynamic Testing of Recycled Asphalt  
Prof Dr G Paulmann, Technische Hochschule Darmstadt, the Federal Republic of Germany  
Mix Design in the United Kingdom  
Dr Richard Salter, University of Birmingham, United Kingdom  
Panel discussion  

#### Alcohol and Drugs

**8.30—12.00**  
Chairman: Dr General George Dobias, INRETS, France  
Effects of Minimum Drinking Age on Fatalities in the United States  
Mr Paul Hoxie, Transportation Systems Center, USA  
License Removal at Time of Arrest for Driving While Intoxicated: An Approach with Promise in the US  
Mr John H Lacey, Program manager — Alcohol Studies, Univ of North Carolina, USA  
Drinking and Driving: Institutional and Social Aspects of Law Enforcement  
Dr Jayet Marie Chantal, Institut National de Recherche sur les transports et leur sécurité (INRETS), France  
The Drinking and Driving Problem in Norway  
Dr Alf Glad, Institute of Transport Economics, Etterstad, Oslo  
Enforcement of Drunk-Driving Laws by use of "Per Se" Legal Alcohol Limits: Blood and/or Breath Concentration as the Definition of Impairment  
Dr Wayne Jones, Department of Alcohol Toxicology, National Laboratory of Forensic Chemistry, Sweden  
Driver Improvement and Rehabilitation of DWIs: The Influence of American Approaches on the Establishment of Treatment Programs in Central Europe  
Dr Edgar Spoerer, Inst for Education, Perfect and Driver Improvement, West Germany  
Discussion  

#### Traffic Safety

**08.30—12.00**  
Chairman: Dr A Hitchcock, TRRL and Chairman of the COST Technical Committee on Transport  
Highway through Towns — Road with Safety and Environmental Priority  
Winner of the 1986 Volvo International Traffic Safety Award  
Dr Otto Schiartz, The Road Directorate, Denmark  
Volvo Safety Design Philosophy  
Anders Eriksson, Volvo Car Corp, Sweden  
An Evaluation Study of the Effectiveness of a Combination of Enforcement and Information on Improving Seat Belt use  
Dr C M Gundy, Institute for Road Safety Research (SWOV), Netherlands  
Road Traffic Signing on Two Continents — A call for Harmonization  
Dr Michael Bernhard, Swiss Lighting Assoc (SLG), 3 M Europe Switzerland  
Road Sign Research in the Federal Republic of Germany  
Prof Dr Siegfried Giesa, Hessisches Landesamt für Strassenbau, the Federal Republic of Germany  
Discussion  

#### Highways Operations

**13.30—17.00**  
Chairman: Dr L-E Bergfalk, National Road Administration, Sweden  
Highway Operations Portion of SHRP  
Mr A D Andreas, Dep secretary of Transportation, Washington DOT, USA  
Highway Operations Portion of SHRP  
Mr David Minsk, Research Physical Scientist, US Army, CRREL, USA  
Evaluation of the surface treatment techniques in France (chip seal and other very thin surfacings)  
Dr J Bonnot, Laboratoire central des ponts et chaussées, France  
Development of maintenance management and control Systems  
Dr L-E Bergfalk, National Road Administration, Sweden  
Highway Snow and Ice Control — Nordic Overview  
Dr Kent Gustafsson, VTI, Sweden  
Panel discussion  

#### Driving and the Elderly

**13.30—17.00**  
Chairman: Dr K B Johns, Transportation Research Board, USA  
Experiences in Fatalities by Age and Road User Groups — USA vs Western Europe  
1970 – 1983  
Prof Ruudger Lamm, Clarkson University, USA  
Elderly Drivers in Europe  
Prof Kåre Rumar, VTI, Sweden  
Driving and the Elderly  
Mr Stephen R Godwin, Senior Program Officer, Transportation Research Board, USA  
Elderly drivers and traffic safety in France  
Dir G Dobias/Dr N Muhlrad, INRETS, France  
Driving and the Elderly  
Prof Dr Günter Kroj, Bundesanstalt für Strassenwesen (BAST), the Federal Republic of Germany  
Discussion  

#### Vehicle Performance

**13.30—17.00**  
Chairman: Prof Dr H Praxenthaler, Head of the Road and Traffic Research Laboratory (BAST), the Federal Republic of Germany  
Social, Economic and Institutional Impediments to the Harmonization of Vehicle Safety Standards  
Dr. Christopher Wilson, Department of Transport, Canada  
Headlamp Performance Evaluation Techniques  
Mr Eugene Farber, Principal Staff Engineer, Ford Motor Co, USA  
Computer Controlled Suspension (CCS)  
Lars Runo Tilikas, Volvo Car Corp, Sweden  
A Triangular for All Simulated Car-Driver Situations  
Prof Dr Techn. F Böhm, Technische Universität, Berlin, the Federal Republic of Germany  
Antilock Braking Systems in USA vs Europe  
Dr Olle Nordström, VTI, Sweden  
Periodic Vehicle Inspection in Sweden — Experiences and View Points  
Dr Sven Asander, Svensk Bilprovning AB, Sweden  
Discussion  

#### LUNCH

**12.00**

#### Discussion

**19.00**  
Presentation of the winner of the 1987 International Volvo Traffic Safety Award and music played by the Gothenburg Philharmonic Ensemble  

**20.00**  
Cocktail and Dinner
FRIDAY SEPTEMBER 11

<table>
<thead>
<tr>
<th>CONCRETE AND STRUCTURES</th>
<th>SPEED</th>
<th>CRASHWORTHINESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.30—12.00</td>
<td>8.30—12.00</td>
<td>8.30—12.00</td>
</tr>
<tr>
<td>Chairman: Dir Ivar Schacke, Head of the Danish Road Research Laboratory, Denmark</td>
<td>Chairman: Dr Brian O'Neill, senior vice president, The Insurance Institute Highway Safety (IIHS), USA</td>
<td>Chairman: Professor Bertil Aldman, Chalmers technology, Sweden</td>
</tr>
<tr>
<td>Concrete and Structure Portion of SHRP Mr Howard Newton, Research Director, Virginia Highway &amp; Transportation Research Council, USA</td>
<td>Speed Limit Enforcement in the United States: The problem of Radar Detection Dr Brian O'Neill, IIHS, USA</td>
<td>Collisions Involving Passenger Cars with Driver Side Air Bags: A US-Swedish R &amp; D Project Jan Thorsson, The Foundation for Health and Safety for State Employees in Sweden</td>
</tr>
<tr>
<td>Development in the Netherlands in the field of concrete and structures and concrete block paving Dr Van der Vring, The Netherlands</td>
<td>The Effects of Police Surveillance Strategies Publicity Campaigns on Speeding Behaviour Dr Talib Rothengatter, Traffic Research Centre, Univ of Groningen, The Netherlands</td>
<td>Child Restraints in Europe Thomas Turbell, VTI, Sweden</td>
</tr>
<tr>
<td>Durability of Road and Bridge Structures of Concrete Nordic experiences Dr Bo Göran Hellers, Head of Swedish Cement and Concrete Research Institute, Sweden</td>
<td>Implications of Raising the US 55 MPH Maximum Speed Limit Mr Stephen R Godwin, Senior Program Officer, TRB, USA</td>
<td>The Child Safety in Cars Gerd Carlsson, Volvo Car Corp, Sweden</td>
</tr>
<tr>
<td>Norwegian Practice for Concrete Bridge Deck Protection Dr Erling K Hansen and Dr John E Haga, Norwegian Road Research Laboratory</td>
<td>The Speed Limit Experiments on Public Roads in Finland Dr Markku Salusjärvi, Technical Research Centre of Finland</td>
<td>Side Collisions and Crashworthiness Prof Bernd Friedel, Bundesanstalt für Strassenwesen (BAST), the Federal Republic of Germany</td>
</tr>
<tr>
<td>The use of 2 metre square Precast Concrete Rafts as Temporary, Reusable and Cost-Effective Roads Dr John W Bull, University of Newcastle upon Tyne, United Kingdom</td>
<td>Speed Limits and Accident Consequences and Risks Dr Göran Nilsson, VTI, Sweden</td>
<td>A Systems Approach for Harmonization of Standards Prof Bertil Aldman, Chalmers, Sweden</td>
</tr>
<tr>
<td>Panel discussion</td>
<td>Speed Limit in Rural Areas in Denmark 1973—1986 Dr Hans W Lund, Traffic Safety Research Board, Denmark</td>
<td>Discussion</td>
</tr>
</tbody>
</table>

12.00 LUNCH AND CLOSING REMARKS
"HIGHWAY OPERATIONS PORTION OF SHRP"

A D Andreas
Deputy Secretary of Transportation
Washington State Department of Transportation

ABSTRACT

Maintenance practices in the United States for streets and highways vary widely among state and local agencies. Only a fraction of highway research resources have gone to maintenance subjects even though this area is responsible for almost one-third of all highway expenditures.

The overall objectives of the SHRP Maintenance Cost Effectiveness research are to improve management information systems that will provide better capabilities for developing budgets, administering programs, and allocating resources; and to make technological improvements in equipment, materials and processes that will increase productivity.

The cost effectiveness of various pavement maintenance issues is of primary concern, including flexible pavement treatments such as chip seals, thin overlays, slurry seals and crack sealing. Treatments for rigid pavements, including joint sealing, crack sealing and undersealing will be addressed.
MAINTENANCE COST EFFECTIVENESS STUDIES FOR THE STRATEGIC HIGHWAY RESEARCH PROGRAM

by

A.D. Andreas
Deputy Secretary of Transportation
Washington State Department of Transportation

International Conference
Goteborg, Sweden

Roads and Traffic Safety on Two Continents

September 9-11, 1987
ABSTRACT

MAINTENANCE COST EFFECTIVENESS STUDIES FOR THE STRATEGIC HIGHWAY RESEARCH PROGRAM

Maintenance practices in the United States for streets and highways vary widely among state and local agencies. Only a fraction of highway research resources have gone to maintenance subjects even though this area is responsible for almost one-third of all highway expenditures.

The overall objectives of the SHRP Maintenance Cost Effectiveness research are to improve management information systems that will provide better capabilities for developing budgets, administering programs and allocating resources; and to make technological improvements in equipment, materials and processes that will increase productivity.

The cost effectiveness of various pavement maintenance issues is of primary concern, including flexible pavement treatments such as chip seals, thin overlays, slurry seals and crack sealing. Treatments for rigid pavements, including joint sealing, crack sealing and undersealing, will be addressed.
INTRODUCTION

While state and local governments in the United States annually spend more than $15 billion to maintain a four-million-mile network of roads and streets, little research has been conducted to improve these operations. Because of the large sums of capital funds that have been spent to construct the federal Interstate highway system and other roads to meet the needs of expanding urban areas, most research has focused on new construction. In addition, no single maintenance project in one state is large enough to warrant expenditures of research money.

In order to focus attention on maintenance activities, the Strategic Highway Research Program (SHRP) proposes to spend $20 million dollars over a five-year period. This paper will describe the proposed maintenance activities (1, 2).

The objectives of this research effort are to provide highway personnel with

- management information systems that will provide better capabilities of developing budgets, administering programs and allocating resources, and
- technological improvements in equipment, materials and processes that will increase productivity (2).

BACKGROUND

Potential

The money spent on highway maintenance is being driven upward for three basic reasons:
while centerline miles are not increasing substantially, more lane-miles are being paved and we have added many high-maintenance appurtenances, such as signs, lighting, guard rails and crash cushions;

the roads constructed in the 1950s and 1960s (much of the Interstate system) are now wearing out and experiencing increased loads;

the costs of labor, materials and equipment are increasing; and

increasing vehicle miles traveled on highways is adding to maintenance costs.

The combination of this upward spiral of costs with the lack of knowledge about the cost effectiveness of various maintenance activities makes the potential for research great. Even a 1 percent increase in productivity would result in an annual savings of $150 million.

Research Needs

In the last two years the Federal Highway Administration (FHWA) and the Transportation Research Board (TRB) have funded maintenance needs studies (3, 4). These studies generated some resources for research but not a continuing, long-term effort to address maintenance issues.

Past maintenance research projects were too narrowly focused and not conducted over a period of time long enough to measure the cost effectiveness of the maintenance. For example, the evaluation of a particular pavement surface treatment with one material, on a particular road, for given weather conditions, does not provide the needed information.
SHRP will provide resources for long-term research with experimental designs that should produce information on which maintenance methods are most cost effective.

PROGRAM IDENTIFICATION

Background Material

Before the final SHRP maintenance program was proposed, a literature search was conducted and extensive agency contacts were made. The literature review (2) uncovered material that was useful in identifying problem areas and served to reinforce the idea that the SHRP is needed.

Agency contacts were important because much of current maintenance knowledge is not available in published form but rather resides with maintenance personnel. These contacts and the literature provided the needed background information for the program advisory committee.

Advisory Committee

An advisory committee with 35 members was appointed to identify maintenance research projects and to provide guidance on the prioritization of these projects. Committee members had diverse backgrounds, as shown in Table 1.

Eight projects were initially identified by the advisory committee for evaluation. Those projects were discussed and evaluated for the SHRP. Table 2 shows the results of this evaluation. In subsequent meetings these topics were refined and topics were added as necessary. The high ranking
of "maintenance effectiveness" indicated a desire to follow through with a rigorous comparison of maintenance techniques.

RESEARCH PLANS

The maintenance of roadway surfaces is the largest single requirement of agency maintenance budgets. The SHRP maintenance program is focusing its efforts on pavement repairs.

Table 3 outlines the proposed research topic areas and initial budget allocations. Additional details on these topics will be provided in the paragraphs below.

Quantifying Pavement Maintenance Effectiveness

Budget restrictions have forced highway agencies to extend pavement life as long as possible before major improvements are made. While many different pavement maintenance treatments are practiced, little is actually understood about their cost effectiveness.

Studies are needed to monitor in-service pavement treatments under the following conditions:

- traffic volume (low-medium),
- temperature zone (freeze-not freeze),
- moisture zone (wet-dry), and
- pavement condition (slight, moderate, severe cracking).

For each of the above conditions, an objective measurement standard must be developed and applied.
Objectives

The objectives of this study are the following:

- to develop a database that will permit increased understanding of the effectiveness of different maintenance treatments in extending pavement service life or reducing the evidence of pavement distress,
- to consider when in the pavement surface life-cycle resurfacing should take place.
- to evaluate the effectiveness of different pavement maintenance treatments in extending pavement service life, and
- to establish a study methodology that can be followed by highway agencies to evaluate any maintenance treatment (2).

Approach

The study will last for five years and will address both rigid and flexible pavements. After an initial evaluation of various treatments available, the following were chosen for study:

- flexible pavement
  - chip seals
  - thin overlays (under 3/4 inches)
  - slurry seals
  - crack sealing

- rigid pavement
  - joint and crack sealing
  - undersealing

This study will be coordinated with the Long-Term Pavement Performance (L-TPP) effort and the SHRP sites will be selected to provide a cross-section of conditions to satisfy the experimental design. As shown
in Figure 3, the study will first develop an experimental design, then a plan to implement the design. The effectiveness study will be implemented and data collected, an evaluation will be performed, and finally a training package will be developed.

**Measuring Systems and Instrumentation for Evaluating Pavement Maintenance Effectiveness**

A crucial part of any adequate management system for pavements must include methods for measuring treatment effectiveness. Therefore, better and more cost-effective methods for measuring conditions such as cracks, holes, faults, voids under pavement, bumps and slippery spots need to be developed. Many agencies currently rely on human observation, which has not always proven to be effective.

This project will investigate both measurement instruments and systems to utilize the data for pavement evaluation.

**Objectives**

The objectives of this study are the following:

- to identify pavement conditions and factors influencing these conditions that must be measured to evaluate the effectiveness of pavement maintenance treatments,
- to identify equipment, instrumentation or methods that can be used to measure the items identified above,
- to develop equipment or instrumentation where no suitable devices exist,
- to develop standard procedures to be followed in making measurements with each identified or developed device,
to develop standard procedures to be followed in reducing each measurement, and

- to prepare instruction and training materials for operating devices and reducing measurement data (2).

**Approach**

This study will begin with an evaluation of existing measuring systems and instrumentation. Devices will be tested in a common environment and evaluated within a set of criteria. Following testing of existing systems, new systems will be designed and prototypes developed if no existing system fulfills expectations. Training materials will be developed as appropriate.

**Improved Materials and Equipment for Pavement Surface Repairs and Crack Filling**

Labor costs are by far the largest share of a maintenance budget. Improvements in materials and equipment may possibly contribute to lower life-cycle pavement maintenance costs. In urban areas where high vehicle volumes make maintenance expensive and risky, new methods and materials that are faster and more durable are required.

**Objectives**

The objectives of this study are the following:

- to identify materials, procedures and equipment for patching localized holes, repairing and other deteriorated pavement conditions in flexible and rigid pavements that are more effective in preventing pavement deterioration and more efficient than existing methods,
to identify materials, propose procedures and specify equipment to use in filling/sealing cracks in flexible pavements and joints in rigid pavements that are more effective in preventing the intrusion of water into the pavement structure and that are more efficient than existing methods, and

to provide estimates of material and labor resources required for each material/equipment/method system for unit quantities of work accomplished (performance standards)(2).

**Approach**

Initially available information on materials and equipment will be studied and evaluated. Laboratory and field testing of the most promising materials will be undertaken. Many products have not yet been adequately compared with other products. In addition, many new products may not have been used in highway maintenance activities. This effort will demonstrate their effectiveness under varying field conditions. Following the evaluation of existing equipment and products, new equipment needs will be disseminated to the private sector for the development of a prototype. This prototype will be evaluated and final design specifications will be set. Long-term field tests (one to three years) of materials identified earlier will be designed and implemented. Once again, documentation and training materials will be provided.

**Pavement Maintenance Work Zone Systems to Improve Worker and Motorist Safety**

The National Safety Council reports that approximately 500 highway maintenance workers are killed each year, making highway
maintenance the second most hazardous occupation in the country. Tort claims from accident victims have risen dramatically in recent years and promise to consume a significant share of agency resources. Work zone safety is clearly in need of research.

Objective

The objective of this study is to develop improved materials, equipment and procedures to minimize the hazard to motorists and maintenance workers during pavement maintenance activities.

Approach

The effort will focus on work zone safety for surface repairs and joint and crack sealing. Methods to quickly install and remove traffic control devices while maintaining traffic flow will be studied. Automation and control device design for safety and effectiveness will be considered.

Existing traffic control devices and procedures will be evaluated. Field studies will be used where they are necessary to close gaps in knowledge. Guidelines will be created for new traffic controls and these will be field tested and evaluated. Training materials will be developed to assure easy implementation.

Media Evaluation and Implementation Research in Highway Maintenance

A great deal of research remains on the shelf because of a lack of attention to effective technology transfer techniques. The highway maintenance community is not used to implementing research results. The medium of transfer must be matched with the materials and audience to be effective. This project will provide guidance on training materials and methods.
Objectives

The objectives of this project are as follows:

- to coordinate with SHRP contractors the development of their information and implementation materials to achieve greater effectiveness and continuity and to identify the most appropriate user constituencies for the results of each project,

- to evaluate the effectiveness of various media in communicating the needs and benefits identified in SHRP maintenance research to each of the appropriate constituencies,

- to produce for each SHRP maintenance technical research project a range of specialized implementation modules to maximize communication effectiveness. These will be individualized for various constituencies using technical information from the SHRP maintenance research projects and the most effective media for each of the maintenance constituencies.

Approach

All methods, including computer, video and electronic systems, will be identified and evaluated. This project will assist other SHRP researchers in their development of materials.

Specifically, this project will first gather information on existing implementation materials and evaluate their effectiveness. Target audiences will be identified and matched with appropriate training
techniques. Information modules will be developed for each maintenance activity.

CONCLUSION

The first two projects described will improve the management process by (1) quantifying pavement maintenance effectiveness and (2) demonstrating methods for measuring conditions. The second two projects will provide technological improvements by (3) developing improved materials and equipment and (4) improving work zone traffic control. The final project will provide the means for implementing research results through (5) media evaluation and implementation.

This program of highway maintenance research totals over $20 million and promises to provide significant advances in the cost effectiveness of maintenance activities.

REFERENCES


### TABLE 1
**SHRP MAINTENANCE COMMITTEE**

<table>
<thead>
<tr>
<th>Organization</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>State DOT</td>
<td>14</td>
</tr>
<tr>
<td>Federal</td>
<td>2</td>
</tr>
<tr>
<td>County</td>
<td>2</td>
</tr>
<tr>
<td>City</td>
<td>2</td>
</tr>
<tr>
<td>Consultants</td>
<td>3</td>
</tr>
<tr>
<td>Industry</td>
<td>4</td>
</tr>
<tr>
<td>University</td>
<td>6</td>
</tr>
<tr>
<td>TRB</td>
<td>1</td>
</tr>
<tr>
<td>Port Authority</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

Table 2. Initial Maintenance Project Evaluation

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Overall Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing Equipment</td>
<td>52</td>
<td>3,4</td>
</tr>
<tr>
<td>Maintenance Effectiveness</td>
<td>78</td>
<td>1</td>
</tr>
<tr>
<td>Improved Equipment</td>
<td>52</td>
<td>3,4</td>
</tr>
<tr>
<td>Improved Materials</td>
<td>49</td>
<td>5</td>
</tr>
<tr>
<td>Interactive Graphics</td>
<td>22</td>
<td>7,8</td>
</tr>
<tr>
<td>Training</td>
<td>56</td>
<td>2</td>
</tr>
<tr>
<td>Expert Systems</td>
<td>44</td>
<td>6</td>
</tr>
<tr>
<td>Public Consequences</td>
<td>22</td>
<td>7,8</td>
</tr>
</tbody>
</table>
Table 3. Proposed Research Plan on Maintenance Cost Effectiveness

**Improved Management Processes**

<table>
<thead>
<tr>
<th>Project 3-1</th>
<th>Quantifying Pavement Maintenance Effectiveness ($6,050,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 3-1.1</td>
<td>Detailed experimental plan</td>
</tr>
<tr>
<td>Task 3-1.2</td>
<td>Implementation plan</td>
</tr>
<tr>
<td>Task 3-1.3</td>
<td>Implementation</td>
</tr>
<tr>
<td>Task 3-1.4</td>
<td>Pavement treatment effectiveness evaluation</td>
</tr>
<tr>
<td>Task 3-1.5</td>
<td>Training package</td>
</tr>
</tbody>
</table>

**Project 3-2** Measuring Systems and Instrumentation for Evaluating Pavement Maintenance Effectiveness ($3,500,000)

| Task 3-2.1 | Existing measuring systems evaluation |
| Task 3-2.2 | New systems terms of reference |
| Task 3-2.3 | Prototype equipment fabrication and testing |
| Task 3-2.4 | Training package |

**Technological Improvements**

<table>
<thead>
<tr>
<th>Project 3-3</th>
<th>Improved Materials and Equipment for Pavement Repairs and Crack Filling ($6,300,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 3-3.1</td>
<td>Available materials survey</td>
</tr>
<tr>
<td>Task 3-3.2</td>
<td>Available equipment survey</td>
</tr>
<tr>
<td>Task 3-3.3</td>
<td>Laboratory and field testing of materials</td>
</tr>
<tr>
<td>Task 3-3.4</td>
<td>Develop equipment</td>
</tr>
<tr>
<td>Task 3-3.5</td>
<td>Long-term material field testing</td>
</tr>
<tr>
<td>Task 3-3.6</td>
<td>Training package</td>
</tr>
</tbody>
</table>

**Project 3-4** Pavement Maintenance Work Zone Systems to Improve Worker and Motorist Safety ($2,900,000)

| Task 3-4.1 | Evaluate devices and procedures |
| Task 3-4.2 | Guides for new traffic controls |
| Task 3-4.3 | New traffic control development and testing |
| Task 3-4.4 | Training package |

**Implementing Research Results**

| Project 3-5 | Media Evaluation and Implementation Research in Highway Maintenance ($1,300,000) |

Source: Ref. (2)
SHRP HIGHWAY OPERATIONS PROGRAM

L David Minsk, Research Physical Scientist, US Army CRREL, Strategic Highway Research Program, Washington, USA

Highway maintenance consumes an increasing proportion of the motorists' tax dollar as the transportation infrastructure ages, but improvements in equipment and techniques have not kept pace with the demand for more effective and responsive solutions. A conservative estimate of the annual expense involved in the physical maintenance of the highway system in the United States is $15 billion; an additional estimated $2 billion is spent on snow removal and ice control. Size, weight, and volume of traffic is increasing on a network built largely 20-30 years ago to specifications less demanding than today's. Not only is the cost for maintenance increasing as a consequence, but maintenance is a labor-intensive activity and thus sensitive to inflationary pressures. Snow and ice control presently represents a significant cost both in its performance and in the delayed effects of mechanical and chemical treatments. Less than 1% of federal highway research funds have been spent on pavement maintenance and snow and ice control. The research to be initiated the first year of SHRP will address high priority needs, including the effectiveness of six pavement maintenance treatments, improved materials and equipment for pavement surface repairs and crack filling, increasing maintenance work zone safety, methods of ice-pavement bond prevention and destruction, improved displacement plow designs for a range of snow conditions, development of standard procedures for evaluation of deicing chemicals, and development of an integrated storm monitoring/warning system and modern communications network to improve responsiveness and cost effectiveness of snow and ice control. Studies to follow later in the program will develop measuring methods and instrumentation to quantify pavement conditions and the factors influencing them, and develop implementation techniques for putting research results into practice.
The most comprehensive multidisciplinary, coordinated, long-term, and well-funded research program in snow and ice control on roads and highways reported in the world's literature is now underway. This represents an unparalleled opportunity to improve the capability of all northern countries to provide safe and serviceable highways during winter conditions and to do so at less cost and with reduced environmental damage compared to contemporary techniques.

The $8,000,000 allocated to this SHRP research area will not solve all the problems or develop all the equipment and techniques that may be needed. The intent from the earliest planning was to consider implementation of snow and ice control from the viewpoint of a complex system, and to devote the major effort to solving the most pressing needs while providing the foundation for continuing refinements. It has also been viewed in the context of a cooperative effort whereby other U.S. and foreign agencies would fund projects to complement the SHRP studies, particularly the studies proposed in the initial SHRP research plan but eliminated because of funding constraints (these are described later).

Snow and ice control is indeed complex. Let's review the unfolding of a storm scenario and identify the disciplines
involved and knowledge needed. First is storm forecasting, detection, and warning—meteorology and electronic weather probing provide these means. Communication between the forecasters and the maintenance operation forces, and between those forces and the public, is the next requirement—communication science and telecommunications engineering are involved. Related technology is needed for the deployment and management of the snow and ice control operation. Physical snow removal utilizes mechanical engineering, and the physics and dynamics of materials. Chemical ice control requires knowledge of the properties of chemicals, their interaction with materials of construction and with the environment—chemistry, chemical engineering, and environmental sciences are the requisite disciplines. Thermal engineering, physics, electric and electronic engineering, and materials sciences all play a role in various methods of ice detection and pavement modification to reduce ice adhesion. Clearly, a multidisciplinary approach is required.

Research areas. With only rare exceptions, all previous research on snow and ice control has been approached empirically, dealing with a narrow aspect of a problem and generally resulting in limited accomplishments incommensurate with the cost. The approach taken in planning the SHRP snow and ice control program has focused on three
areas of research, commencing with fundamental studies to provide the knowledge base needed for later detailed specific studies. The three areas are as follows:

- The nature and mechanism of bonding of ice to pavements and methods for preventing or destroying the bond.

- The mechanics of flow of fluidized particulates with application to the improvement of displacement plow design and snow drift control.

- Methods of winter maintenance incident detection and response, with application to storm detection/warning, pavement surface condition monitoring, and communication and management technology for system control.

Ice-pavement bonding. Ice and refrozen compacted snow can bond so tightly to pavement that present mechanical methods of removal are inadequate or else result in surface damage. Chemical methods of removal are successful to varying degrees, but a price is paid in pavement surface damage, structural and utility deterioration, vehicular corrosion, or environmental harm. The use of salt (sodium chloride) has become so widespread because it is cheap, readily available, inexhaustable in supply, and effective at most commonly experienced temperatures. This dependence on salt is low in first cost but high in total cost. Knowledge of the nature
of the bond between ice and pavement materials and the mechanism by which it develops forms the basis for the first two contracts to be awarded by SHRP. These are parallel efforts which have the common thread of investigating the ice-pavement bond but which will take two different approaches, one from the point of view of bond prevention and the other from that of bond destruction. In consonance with the goals of SHRP, it should be emphasized that these fundamental studies are intended to provide the basis for projects to follow that will pursue the most promising implementable approaches. This strategy is considered so important to the success of a significant portion of the snow and ice control program that nearly 20% of the total available funds will be devoted to these fundamental studies.

Projects to develop practical, implementable techniques and equipment which will be based on the knowledge provided by the fundamental studies include research on physical surface modification, chemical surface modification, and contact and non-contact snow/ice physical disbonding. A number of materials and techniques now used or proposed fall into these categories, e.g., deformable surfaces (Rubit or PlusRide), chemically impregnated pavement wear courses (Verglimit), grooved pavement, serrated or vibrating cutting edges on blades, electromagnetic radiation such as
microwaves, and pavement scrapers (underbody blades). All of these approaches have met with varying degrees of success but research can improve their effectiveness and provide new approaches. Another area of research involves improvement of deicing chemicals. Since much effort and money have been expended on the deicing effectiveness, the effects on materials of construction, and environmental fate of calcium magnesium acetate (CMA) by many agencies around the world, no SHRP funds will be spent on additional CMA research unless gaps in our knowledge preventing its full implementation are identified. Instead, SHRP will devote effort and money to the identification of other improved, effective candidate deicing chemicals and to the formulation of a standard procedure for testing and evaluating deicing chemicals that are developed commercially. Since sodium chloride will continue to be used because of its low cost and ready availability, a subtask of this effort will investigate the characteristics of this deicing chemical and how to improve its performance.

Fluidized snow and its applications. The density and water content of snow can profoundly affect its bulk properties, such as compressive and tensile strength, and its fluid flow. Disaggregated snow, i.e., snow that has been broken into small particles or is falling in discrete form, can exhibit flow properties ranging from a resemblance to
blowing feathers to the flow of a viscous fluid. The fluid dynamics of snow is important with regard to the improvement of both displacement plow design and to snowdrift prevention or modification. Both of these design goals have been attempted in the past, both analytically and by model studies using either synthetic or model snow. These approaches are difficult, time-consuming and expensive to implement because many parameters must be changed to cover the range of conditions present in the real world. The potential exists to apply computer graphics equipment and techniques used in computer-aided design as fast, relatively inexpensive tools to the study of fluid dynamics of snow and to apply those techniques to the design of displacement plows and snow fences.

**Storm monitoring/communications technology.** Snow and ice control is the single most costly maintenance function performed by many northern states and cities. There is frequently a reluctance to spend adequate money to equip an organization to perform most effectively and efficiently since there is little to show for the task at the end of the winter. A conservative estimate of the direct cost for snow and ice control by the states of the U.S. alone amounts to about $1500 million. Though statistics for cities are not as complete and reliable as for states, an equal amount is
probably spent by those jurisdictions based on the
distribution of road mileage.

Control of snow and ice is achieved with minimum cost and
with minimum delay to the motoring public if remedial
treatment is initiated at the beginning of a storm and the
appropriate treatment selected on the basis of knowledge of
the pavement surface condition and the present and
forecasted weather. This requires mobilization and
deployment of maintenance forces and effective communication
of conditions within the organization and to the public
prior to the storm. If the storm warning is false, resources
are wasted by the unnecessary mobilization and the
organization's credibility is damaged; if it is late, extra
expenses are incurred and the return of the system to normal
is delayed. Accurate forecasts quickly disseminated to the
maintenance organization and then to the public are the
first requirement for an effective system.

Continuous assessment of the pavement surface state at
selected key stations throughout the road network is
necessary to provide the information for a responsive and
optimum treatment. Rapid and continuous communication within
the organization and with surrounding jurisdictions is
necessary for effective control of snow removal forces. In
summary, the objective of this research is to assemble into
an integrated system existing technology for storm
forecasting, pavement ice detection, and communications technology to improve the capabilities for making rapid, cost-effective responses to winter maintenance requirements with minimum inconvenience to the motorist and with maximum public awareness of road conditions.

Excluded studies. Four projects were identified as worthy of consideration but were eliminated from the final research program because of funding constraints. They are described in the final report of the research plans with the expectation that other agencies may consider their implementation. Presented here is a brief description of each.

Thermal methods of snow and ice control. Snow or ice will not bond to a surface remaining above 0°C even though accumulations might continue to a considerable depth. Confining the introduction of thermal energy into the interfacial layer is energetically the most efficient approach, and is best accomplished by heating the surface of the pavement. Providing thermal energy in the quantities necessary by using fossil fuel sources has, however, proved uneconomic in all but the most critical applications. Low grade heat from localized earth sources has been practical for relatively limited area heating with heat pipes, but this is inadequate for the extensive area heating that would
be required for a major urban system. Heat pipes for coupling low grade energy sources to pavements for snow and ice control have been investigated in the United States, Japan, and Germany, and several small installations have been built. No studies have been made on the economics and feasibility of scaling up to extensive pavement heating systems. In an urban environment both the need for a positive, rapidly responsive snow and ice control system and the availability of vast quantities of low grade heat from sewage, industrial waste, or water bodies may converge to justify its implementation. However, economic viability and engineering feasibility must be demonstrated. The objective of this task is the investigation of the practicability of utilizing low grade heat from a variety of urban sources and transporting the energy for distribution to extensive highway sections.

**Test and evaluation of CMA.** This study would be necessary only if current research on effectiveness of calcium magnesium acetate as a deicer, development of low-cost production methods, and investigation of the environmental consequences of its use is inadequate for selecting this product as a preferred noncorrosive deicing chemical.

**Improvement of resource planning and program evaluation.** No universal and practicable method is available
to maintenance management for evaluating the quality and effectiveness of existing snow and ice control programs or for designing new and more effective programs.

The objective of this study is to develop a model for use in program evaluation and design. It would be implemented by making case studies to establish the characteristics of effective winter maintenance organizations, defining requirements of those organizations, and developing an expert system.

Demonstration of technology-based winter maintenance operation systems. Many of the materials, procedures and equipment that may be produced by the approved SHRP research program may be most effective when used in conjunction with other new or existing systems, though conflicts may develop that must be avoided. The intent of this project is to investigate problems that may arise in implementing multiple technologies and equipment and to devise system integration procedures. The large scale nature of this study and the consequent projected high cost led to its elimination from the final program and the substitution of independent field testing of the products of each study. Testing and evaluation of a fully integrated system will be necessary at some point to realize the full potential of the separate research products.
SOME ASPECTS OF THE RESEARCH CARRIED OUT IN FRANCE IN THE FIELD OF S.H.R.P

Dr Jacques Bonnot
Laboratoire central des ponts et chausses
France

The paper will be a general presentation of the research work which is carried out in L.C.P.C (Public Works National Research Institute of France) in the field of the 6 Technical Research Areas of S.H.R.P, with emphasis on TRA 1 "Asphalt Characteristics", TRA 2 "Long Term Pavement Performance", and TRA 3 "Maintenance Cost-Effectiveness".

The situation in France and in the United States will be compared as regards the aims of the research, and the construction and maintenance techniques used in the field. The paper will present some examples of the methods used and the results obtained, which are of special interest for S.H.R.P, mainly in the field of:

- the study of the colloidal structure of asphalt cement
- the characterization of the mechanical properties of asphalt cement
- the relationships between asphalt chemical and physical properties
- the modification of asphalt cement, with emphasis on the relationships between the microstructure of polymer modified asphalts, and their mechanical properties; and on the relationships between the mechanical properties of the binder and the performance of surface dressing
- the testing and measuring of asphalt-aggregate mixtures
- the evaluation of pavement condition
- the weigh-in-motion systems
- the accelerated loading of pavement using a circular test track
- the performance of surface dressing and slurry seal on highly trafficked roads
- the evaluation of the equipment for surface dressing work.
I. SURFACE DRESSINGS, SLURRY SEALS AND VERY THIN HOT BITUMINOUS MIXES

1.1. REPORT ON THE EFFICIENCY OF SURFACE DRESSINGS (CHIP SEALS) IN FRANCE.

Description

Even before the appearance of new guidelines made necessary by the energy crisis, the French Highway Administration has started a research program designed to improve and extend the field of use of surface dressing for maintenance of the national road network, in particular of overlaid sections, given the qualities of skid resistance and impermeability offered by this very thin technique. The results achieved have allowed the improvement of the guidelines. The concern to achieve savings in the use of oil products was an additional element justifying the continuation of these studies in order to extend the use of surface dressings to maintenance of pavements with heavy traffic, and wearing courses for new or overlaid pavements with light traffic as a substitute for bituminous mixes. To day, more than 300 million of square meters of surface dressing are applied annually in France by Government contractors on all types of pavements.

We shall describe the main aspects of results achieved on:

- the components, aggregates and binders,
- the formulation design methodology,
- the equipment,
- the implementation and its checking

This paper aims to provide the present or future users of this technique, with the key points so they may benefit from the French experience and particularly be able to adapt it to contexts which are sometimes very different.

THE COMPONENTS

Binders

There is a great variety of bituminous binders for surface dressings available in France, each type differing in chemical nature, and also subdivided into several categories of consistency and covered by precise specifications.

Modified binders for surface dressings (fluxed binders and emulsions) essentially based on a modification of traditional binders by incorporation of polymers are not covered by any particular specifications, although presently representing 15% of the quantities placed annually in particular on pavements with very heavy traffic. However, a complete in laboratory design and characterization methodology is being studied by L.C.P.C.

Binders for surface dressings are manufactured at a number of production centers all over the country and normally supplied in tankers, ready for use.
The engineer can then make a trade off between the economic data and the technical necessities governing the work to be carried out. On this later point, there are several often contradictory considerations to be taken into account:

- it is easier to use a fluid binder than a viscous binder

- withstand of the surface dressing immediately after application means that the consistency of the binder must increase as the aggressivity of the traffic and the temperature increase (seasonal effect)

- formation of the structure of the dressing requires a sufficiently fluid binder, the lighter the traffic, the longer the binder must remain fluid.

Aggregates

In France aggregates are covered by specifications which define different qualities depending on the intrinsic properties of the rock (hardness, resistance to abrasion and polishing) and those linked to production (dispersion of particle size, crushing rate, shape, clean condition, ...)

Quarries in continuous production ensure a sufficient supply of chippings to meet the requirements with the quality criteria thresholds becoming increasingly demanding (except for clean condition) as the constraints on site increase, directly linked to the volume and nature of the traffic forecast.

The binder-aggregates combination

Tests which can be carried out rapidly at low cost using simple equipment are used to assess overall adhesion and active and passive adhesiveness. In particular they review any problems as to the clean state of aggregates, resistance to stripping of the binder by water and ensure that the wetting of the aggregate by the binder will be effective even under damp conditions. They also constitutes a vital aide for the study of doping (choice and dosing of the product) or special aggregates treatments (dust removal, washing, pretreatment and pre-coating)

The structures

By its double discontinuity (binder and aggregates in consecutive layers and generally alternative) surface dressings offers enormous possibilities in the combination of different courses.

The usual combinations in France are as follows:

- single surface dressing 6/10 for pavements with light traffic, and sometimes 10/14 for heavier traffic

- single surface dressing with double chipping 10/14, 4/6 normally using modified binders for pavements with fast and intense traffic flows, due to its anti skid characteristics

- double surface dressing 10/14, 4/6 for pavement with heavy traffic or when surface sealing is particularly sought.
A special "sandwich" structure is presently being developed. It comprises a binder course between two aggregates courses. One of its main qualities which partly explains its success, is that it overcomes heterogeneity of the support which facilitates determination of the average binder dosing while ensuring wetting "from the top" of the aggregates in the first layer.

The formulae

The preliminary selection steps having been completed, it now remains to determine the formula best suited to the type of work. This formula should take into account several elements:

- the type of structure (monocourse, double chipping monocourse, dual course)
- the size of the aggregates for each course
- the amounts of binder and aggregates in each course

Briefly, we can consider that

- large aggregates are more resistant than small aggregates
- dosing is related to their covering capacity,
- multicourses increase the durability of the dressing and can carry heavier traffic flows
- binder dosing should be suited to the size of the aggregates the nature and state of the support and will increase as traffic decreases.

Economic considerations guide our choice insofar concerns aggregate size and structure given that increase in particle size and number of courses produces parallel increase in materials consumption and implementation costs. Depending on the life time aims we therefore look for the best quality/cost trade off. The directive summarizes the average formulae normally applied in France.

Application equipment

Binder spraying equipment

The stock of spraying machines available in France is estimated to approximately 1200 vehicles. Certain machines are fairly old, (fifteen to twenty years, or more) and are maintained as standby. However, some two thirds of the vehicles in service are less than years old or are fitted with equipment of recent design.

A study carried out in 1986 on 62 "automatic dosing" spraying machines showed that the average difference between theoretical dosing and actual dosing was - 23 g/m² with a standard deviation of 80g/m² which demonstrates the efficiency and reliability of this modern equipment.

Figure 1: Relationship between dosing carried out on the pavement and speed of movement of an automatic spraying machine
Detailed studies have been made of spraying machines using the test bench at the SEMR (Road building equipment test station) as result of which optimum operating conditions have been defined and French designers provided with informations enabling them to design high quality equipment.

This bench is also used for periodic testing of spraying machines and their adjustment now is to achieve a transverse variation coefficient (CV = $\frac{m}{m}$). Routine checks are then carried out on site using a plate insofar as concerns average dosing, together with periodic checks of transverse distribution using a specially equipped rod or the radioactive tracer method. The following thresholds represent a correct level of quality to be found during equipment acceptance tests:

- average dosing observed within 5 %
- transverse variation less than 10 %.

Chipping spreaders

There are some 2600 chippings spreaders available in France divided into three groups

- towed chipping spreaders which are the most common comprise a spreading device secured to the back of a tipper truck
- pushed chipping spreaders composed a chipping hopper and a system of attachment to the tipper truck which drives it. This type of machine is rare.
- Self propelled chipping spreaders based on the principle of finishers for bituminous mixes. The average dosing is relatively easy to achieve with much better transverse regularity than with the traditional towed type chipping spreaders. There are about a hundred of these machines in France which have been recently introduced. Prototypes of variable spreading width machines giving great flexibility of use are being developed; a similar effort to that made for binder spraying machines is at present being diverted to the design of chippings spreaders.

The Public Works technical departments designed and produced a test bench for chipping spreaders at the Blois SEMR which features continuous recycling of material. This test bench came into service in 1984. The device to measure the veil produced by the chippings is an opto-electronic system composed of a light box and an electronic camera with a CCD line array as a sensitive element working at ground level. The signals supplied by the camera are fed to a micro computer. Average dosing is determined by means of a weighing table installed on a chipping return belt.

Thick dressings (membranes)

A new generation of surface dressings appeared in the 1980's. These are called "thick" coats dressings owing to the amount of binder used. In fact for 10/14 single surface dressing, the quantity of binder may be doubled that used in traditional technique. The binders used are modified bitumens or rubber bitumens containing very little solvent. The chippings are normally 10/14 coated or spread hot in order to obtain good adhesion because of the high viscosity of the binder. These dressings are particularly designed for the maintenance of cracked pavements in order to ensure good sealing at the same time restore the service characteristics in durable fashion. At present, some 500 000 m² of surface is treated every year.
Results

The surface dressing technique is widely used in France on all roads. It is prevalent on district and municipal roads but also used on the national network to regenerate the surface characteristics (roughness and impermeability).

The length of national roads dressed in this way is at present 25 % and the amount of divided highways 6 %. In this respect, out of all works carried out on highway A 6 on cement concrete pavement in order to reduce slip surface dressing proved the most efficient. In fact, statistical studies carried out on basis of an accident file enable the comparison of results "before" and "after". They show a reduction of 78 % in the number of accidents on wet pavement. The seriousness was also considerably reduced, average cost going from 87 000 FF before and 33 000 FF after i.e. a decrease of 62 %.

Surface dressing proves to be particularly efficient on heavily trafficked cement concrete pavements (fig.2).

The generalized use of this technique has been made possible thanks to the definition of the conditions necessary for production of quality dressings. In this field, the conditions concerning the aggregates, binders, supports and rules governing application are now fairly passed in experience.

NATIONAL SURVEY 1980

Figure 2 : Antiskid characteristics measured on single surface dressings with double chipping having carried a cumulative traffic of $10^6$ heavy goods vehicles.
1.2. USE OF SLURRY SEALS IN RURAL ROADS

History

The technique of bituminous slurry seal imported from the United States achieved considerable development in France in 60s.

The material was mainly composed of crushed sands, or partly crushed or rolled sands of particle size 0/3 or even 0/5, and by a special emulsion generally a cationic emulsion.

Skid resistance of this product was clearly inadequate and they changed very rapidly in a period of time. As result, the technique was abandoned especially in rural roads in the 70s, and its use limited to urban roads.

It was only in the 1980 that a new generation of slurry seal returned to favor in pavement maintenance.

Definition

The use, in France (*), of bituminous slurry seal in rural roads, is linked to the design in 1980 of a technique known as "slurry asphalt concrete" which is characterized by:

1. The use of completely crushed material with good mechanical properties.
2. A richness modulus around 4, i.e. slightly higher than that of hot asphalt concrete
3. Large aggregate size greater than 6 mm
4. Dosing of 15 to 20 kg/m² of dry materials

In the case of heavy traffic flows we also note the use of modified bitumen emulsions

The aim of these modifications is:

- to improve resistance to wear
- to provide acceptable anti skid characteristics,

while remaining within a competitive price range compares with other maintenance techniques.

Field of use of slurry asphalt concrete

The slurry asphalt concrete technique is essentially a very thin surface maintenance technique. It should first provide sealing and skid resistance.

Compared to traditional techniques (surface dressing, thin hot mixes) the slurry asphalt concrete can be used where a surface dressing is unsuitable. For example:

(*) The legal axle weight is 13 tons.
- if the noise level is to be limited,

- if the heavy goods traffic and the site may cause indentation of the aggregates in the support,

- if the support is too heterogeneous.

The limits of use the following

- maximal traffic flow: about 1000 heavy goods vehicles per day, per direction,

- deformability of the support: the support should be in good structural condition,

- rutting: slurry asphalt concretes cannot be used on rutted pavements.

The equipment

New production and spreading vehicles are now available. For example the MACROMIX-PAVER ERMONT SCREG self propelled machine with front loading enables increase in daily output (3000 m$^2$/h) at the same time as providing very good accuracy in production. (fig.3).

![Diagram of SCREG ERMONT front loading machine](image)

**Figure 3**: SCREG ERMONT front loading machine (Screg-Ermont patent)

This machine designed to standard pavement width can easily be transferred from one site to another.

It was awarded with a prize in the Innovative Techniques Competition held in France by the Directorate of Roads.

The market

Since 1980, we note an increase in the amount of surfaces treated. In the last three years (1984, 1985, 1986) the total surface area treated with slurry seal were 3.4, 4.6, 5.8 million m$^2$. {#dry asphalt concretes (particle size greater than 6 mm) represent almost 70% of m$^2$. The market. Their use in rural roads is 30% (1.8 million m$^2$) which is far from neglectable. The binders, modified by addition of polymer represent 50% of the surfaces treated.}
Results

The experience in this field concerns application of up to 6 years old carrying traffic flows from a few tens to several thousands of heavy goods vehicles/day and on very diverse pavement structures.

a) Skid resistance

It is necessary to use a 0/8 or 0/10 formula in order to obtain a level of skid resistance greater than or comparable to that of traditional mixes.

Apart from the global formula and the quality of components preparation of support is a necessary condition for retention of skid resistance over time. In particular, deformation should not exceed 10 mm. The reshaping work required is often carried out using a 0/4 slurry seal method ("two course" technique).

b) Structural behaviour

This technique has no structural effect. In particular, this product does not prevent cracks arising from old pavement.

c) Traffic noise

Which is much less than that of a surface dressing and slightly better than with a traditional mix.

d) Impermeability

For dosings of 15 to 20 kg/m\(^2\), these products ensure acceptable impermeability.

e) Surface appearance

When young, the surface is less even than with other solutions. This surface appearance improves after a bit of time.

Conclusions

In order to be successful this process requires:

- a high level of technical ability

- and great care.

The slurry asphalt concrete technique may run into difficulties if a very low cost is sought, its behaviour may be affected and this must be avoided in particular by making a clear distinction between this technique and other traditional techniques.
1.3. HOT BITUMINOUS MIXES USED IN VERY THIN LAYERS

Introduction

The idea of using very thin techniques to maintain pavements is brought up each time a period of economic difficulties is encountered. In the 1950 - 1960 the use of coated sands was routine practice in order to save a network in a very poor state. From 1965 to 1975 which was a period of strong economy we used only 6 to 8 cm thick mixes which were much less slippery. From 1975 onward, the idea of economic maintenance techniques gradually returned. From the year 1980 it became an economical necessity. In 1987 we can draw an initial balance sheet concerning these techniques some of which are new but very often readapted to suit their time.

Design of these techniques

a) Coated sands with precoated chippings

This technique requires a very even support (less than 1 cm deformation measured with a 3 m rule) or suitably prepared. In order to facilitate penetration of the chippings the sand is usually 0/4 crushed with the addition of a good amount of rolled sand 0/4 (40 %). The considerable amount of binder used (approximately 7.5 ppc) of low consistency.

The 14/18 size chippings are hard rock and are pre coated with 1 % 40/50 hard bitumen.

Traditional application comprises:
- preparation of the support
- spraying of a tack coat (300 g/m$^2$ of residual bitumen),
- application of a layer of coated sand with a finisher (20 mm thick)
- spreading of chippings using a separate machine (7 to 8 kg/m$^2$)
- compacting using a smooth compactor.

In June 1987, some 7 to 8 million m$^2$ of pavement have been surfaced with this type of product in France at an annual rate of 1.5 million m$^2$ (1986)

b) Thin maintenance mixes

These 3 to 4 cm thick mixes are:
- either highly discontinuous (no 2/6 fraction)
- or slightly discontinuous (no 4/6 fraction) with an addition of fines
- or slightly discontinuous with a little rolled sand.

From the point of view of application, there are no particular features which distinguish them from thicker bituminous mix techniques.
In this category of maintenance bituminous mixes, you also find a whole range of special products normally based on modified bitumens and designed as all purpose products.

Thin maintenance bituminous mixes are classified in a technical memo published in 1979. From this date onwards, their use developed steadily until they represented a total of 30 of the annual amount of surface coated, i.e. about 10 million m² per year. The total surface of pavement whose last course is a mix of this type is at least 50 million m² (all products and therefore ordinary bitumen based or modified binders).

c) Very thin bituminous concretes

These appeared on the French market in 1983, with thickness down to 22 mm which represents 45 to 60 kg/m².

Some of the formulae use only pure bitumen.

As for the grading curve the formula used may be continuous but it is usually discontinuous (gap graded).

Particle size may be 0/6 (in the form of bituminous micro concrete), 0/10 or 0/14.

The spreading and compacting equipment has remained completely traditional including systematic use of pneumatic tire compactors.

Many companies have designed proprietary mixes with special features very often concerning the binder used and its dosing.

The use of modified bitumen is systematic.

From the point of view of particle size, the 0/6 and 0/10 which are very discontinuous and very rich in coarse aggregates are most often used and the total fines contents may be normal or very high, depending on the process.

These techniques are likely to accept much greater profile deformation than coated sands with precoated chippings, although deformation must not exceed 13 to 15 m.

Since 1984 or 1985, all French companies offer very thin mixes with special binders. At the end of 1986, the surface was estimated 5 million m²

- 4 million m² for special processes of which 2 million for one product

- 1 million m² for pure bitumen technique

in both cases applications cover all types of traffic and many concern divided highways.

Conclusion

Whereas the use of thin mixes for preventive maintenance has only recently achieved full prominence, the very thin techniques: coated sands with precoated chippings and very thin bituminous concretes started to develop in 1983.

Their present success is achieved to the detriment of all other maintenance techniques.
II. METHODS AND EQUIPMENT FOR ASSESSING MAINTENANCE EFFECTIVENESS

Approaches vary depending on the type problem. Here are two examples:

1. Monitoring and assessment of a technique

The assessment structure is as follows:

- two national project leaders, one laboratory oriented, the other project management oriented. These persons are responsible for the organization from the first premises of the technique through to its industrial development of its monitoring, technical and economic assessment at all stages of its development and eventual promotion and even cancellation of the project if the technique is revealed of being of no interest. At each stage of the development, a decision is taken with regard to continuation of the work.

- these two project leaders are backed up by regional heads who also belong to the regional network of roads and bridges department laboratories (17 throughout France) and are provided with a certain budget.

- the work involves an annual assessment which is communicated to the engineers in the field wherever necessary.

The main techniques monitored at present are as follows:

- pavement retreatment with a hydraulic binder,
- pavement retreatment with a hydrocarbon binder,
- treatment of fine soil for pavement courses,
- techniques which limit the reflection of shrinkage cracks in courses treated with hydraulic binders (including pre-cracking of the course),
- rolled concrete,
- improvement of the surface resistance of cement bound granular materials layers
- previous coated macadam,
- very thin bituminous mixes,
- thick surface dressings,
- slurry asphalt concrete
- "inverted" pavement structures.
2. Choice of a technique: competitions for innovative techniques

In this case project management is looking for a solution to a given problem. For example, several years ago the Roads Department was looking for a maintenance solution which would fall somewhere between surface dressings and 4 cm thick bituminous mix which were the traditional maintenance solutions. A competition was announced. The description of the competition defined the technical, financial and industrial aims. Almost all the major companies submitted offers. It should be noted that this often triggered joint research programmes between several of the partners in the manufacturing chain (producers of materials, manufacturers of equipment, applications). Considerable resources were deployed in order to make a valid assessment of the offers. Following pre-selection, comparative test sites were set up with pre-runs of between 40 and 50 000 m² for the offers selected on paper. A technical, economic and industrial assessment was made. As an example the following investigations were carried out on the comparative test sites:

- assessment of the works (survey of deterioration, transverse and longitudinal eveness, deflection, rutting),
- identification of the products used: physico-chemical analysis of the binders, formulation,
- monitoring of application: conformity progress check,
- condition after application and monitoring: transverse and longitudinal eveness, rutting, adhesion, macrotexture, permeability, deflection, survey of deterioration.

These factors were used to make a choice between the various techniques which were capable of solving the problem posed. Following this, the Roads Director announced the results and encouraged the Department of Highways engineers to use these products.

Use of pavement evaluation equipment - Road Data Bank

Right from the start of its avowed policy of rehabilitation of the 30 000 km long national road network, the French government was careful to provide adequate resources for the preservation of the considerable capital investment made in a systematic strengthening overlay of the road network structures which normally carry a heavy traffic flow.
Although it is impossible to give even a brief description of all the projects which have been completed since this time, we will nevertheless mention a few of the more important:

- continuous improvements made to the Lacroix deflectograph for precision survey of deflections (often less than 20 mm/100);

- systematic use of a profilometer to measure roughness over a range of wavelengths from 1 m to 40 m; this enables an assessment of the efforts made by means of various maintenance techniques in order to correct faults in various ranges of wavelength;

- development of continuous high speed photographic equipment (GERPHO) which provides a record of the condition of the pavements monitored;

- the design of a test for assessing bending deformation at the base of pavement courses by means of measurements made in a core sampling hole (ovalisation test using specific equipment); this enables us to assess the contribution made by a maintenance course to the reduction of stresses in pavement structures;

- design of a continuous pavement thickness measurement process by radar waves (precision plus or minus 0.5 cm);

- systematic evaluation of the behaviour of all strengthening overlay operations carried out on the national road network by means of an analysis of the maintenance needs.

- systematic monitoring of the 200 test sections.

Two detailed examples:

- monitoring of the national road network: for the last 10 years decisions with regard to the maintenance to be carried out on the national road network have been made by means of a method based on the use of the results of measurements made with high efficiency instruments and decision aid diagrams (one for the structure aspect, another for the safety comfort aspect).

In this particular case we used the APLs (roughness measured every four years approximately), the SCRIM (skid resistance - measured every four years approximately) and for annual deterioration survey either a visual survey or a GERPHO survey. This method is used on a network of more than 20 000 km of national roads and highways.
Experience has shown that it is useful for field engineers that those results stored in a Road Data Bank be assembled in the form of a route diagram in which one sheet represents one kilometer of pavement.

Section a contains the characteristics of the pavement (width, composition, maintenance carried out) and section b its condition (results of measurements). This type of monitoring method also enables an assessment of the maintenance to be carried with respect to various parameters (traffic flow, structure, materials, etc.). The result is a continuous evaluation of the structures over more than 20,000 kilometers. This evaluation is especially useful for assessing the efficiency of the various pavement or structural maintenance techniques used.

- the competition for innovatory techniques are already described.

**Piezo-electric cables**

The measurement of traffic flows carried is one of the main components of evaluation of the behaviour of a technique. Piezo-electric cables are used if necessary combined with magnetic loops.

The design of the piezo-electric cable and the associated electronics enable continuous axle weighing and therefore provides the data necessary for calculation of aggressivity.

The cable is cemented into a slot previously prepared in the pavement.

The piezo-electric ceramic acts as a compressed and polarized sensitive element located between the core of the cable and a copper sheet. The cable can be compared to a cylindrical capacitor whose armatures charge electrically as soon as it is subjected to a variation in stress. The voltage which appears between the sheath and the core is proportional to the variation in pressure undergone by the cable. Following amplification of the signal and calibration of the system, it is possible to weigh loads in movement in continuous fashion.

By associating magnetic loops with the piezo-electric cable, the station can also produce statistical results on user speeds, instantaneous flow rate, vehicle silhouettes, etc.
The measuring instruments (cable and loops) are connected to an electronic system which picks up the signals, processes them and stores the results. There are different types of equipment:

  This type of station which is relatively modest has two main functions:
  - to provide statistical results on traffic flows,
  - to pre-select overloaded vehicles so as to optimize statistical weighing operations involving sanctions.

- **S.A.F.T. (Fine Traffic Flow Analysis Station)**
  This station which is more powerful than the previous one produces more detail results on traffic flow (for example: distance between axles, transverse position of the axle on the road, length of the vehicle, etc.).
  It was designed as part of a study on bridge structure fatigue.

### III. MATERIALS AND EQUIPMENT FOR ROUTINE MAINTENANCE (treatment of cracks, small repairs, etc).

Since 1985 and in particular in 1986 an equipment item known as a binder and chippings spreader or sometimes an automatic patcher has been used for routine maintenance. It is designed to produce "partial" dressings for the sealing of pavements exhibiting crazed areas, as a replacement for manual work with the spraying hose. The equipment can also be used for small areas (sealing of localized reshaping, car parks, etc.).

The dressing produced is a single surface dressing (one layer of hot binder or emulsion, one layer of chippings).

**Principle and brief description of the binder and chippings spreader.**

The various devices which provide the different functions are assembled on a carrier. The special feature of this equipment is that it can spread (simultaneously or not) both the binder and the chipping over a variable width and also compact it.
Description of operation

- Two operatives are required.

- The spreader loaded with binder and chippings becomes operational once the rear operative has placed the walkway in position and made the settings: height of the spray-bar, angle of tilt on the skip, etc).

- The driver of the vehicle selects and adjusts his reverse speed in accordance with a predetermined chart so as to produce the desired emulsion dosing (at constant spray height and pressure the binder dosing is controlled solely by the speed of the vehicle).

- Once he has lowered the compacting device the rear operative directs automatic patching in reverse, and in the case of single surface dressing, opening of the nozzle/flap combinations on request to suit the width to be dressed.

- For multi-surface dressing the operation is repeated. Compacting may be finished off if necessary by additional forward and reverse passes.

- Other possibilities may be added to this type of operation:

  - The equipment includes a nozzle for traditional type working.
  - It is possible to spread the emulsion separately from the chippings so as to provide a tack coat.
  - It is possible to spread the chippings only in order to deal with areas which bleed.

- The advantages of Automatic Patching are as follows:

  - Technical:
    Control of aggregate and binder dosing which prevents any over dosing.
    Systematic compacting of the repairs.

  - Economic:
    High efficiency with spreading of up to 9 tones of bitumen emulsion per day, i.e. approximately 5 times more than with the traditional patching methods. Costs per square meter of surface treated are cut by between 40 and 60% (price 5 to 7 frs inclusive of all taxes/m2).
Safety
No personnel working on the carriageway.

Disadvantages
Equipment does not lend itself easily to curing operation.

Some fifty binder and chipping spreaders of this type have been manufactured in 2 years. The demand is very high.

The treatment of cracks and in particular transverse shrinkage cracks due to courses treated with hydraulic binders has been in operation since 1979-1980 using a bridging sealing technique (overbanding).

The technique consists in:
- preparing the crack usually by means of blowing out and cleaning of the crack with a thermo-pneumatic lance. Apart from cleaning the crack, this process forms a certain "reservoir" for the sealing product vertical to the crack. Thus the thickness of the product is greater at this critical point without compromising evenness of the pavement.
- applying a sealing product; in most cases a bitumen with a high polymer or rubber bitumen content which has successfully completed adhesion, crack movement withstand and filling tests.
- applying a very clean fines free sand to the surface in order to protect the sealing product from traffic wear.

As with any waterproofing work great care must be taken with the application. The price varies between 7 and 12 frs inclusive of all taxes/m of crack with an output of between 1 000 and 2 000 meters per day.

This technique is also used on reflexion cracks from cement treated bases before the application of a maintenance wearing course in order to retard reflexion of the crack into the new surfacing.
IV. SAFETY TECHNIQUES AND SYSTEMS FOR USERS AND WORKERS DURING MAINTENANCE WORK

1. Equipment

Two new equipment items are now in use.

a) Transposable marker posts and separator

The problem posed is to install a continuous separator in order to separate two lanes in opposite directions, for example when a changeover is required to a highway pavement. The difficulty is the implementation of such a system in operational fashion.

The transposable separator is composed of NEW JERSEY type cement concrete elements 1.10 m long (weight 650 kg) with flexible keying between them. Laying rates (with cranes) are up to 1 100 to 1 500 m per day. This equipment has a truly separating effect. It is particularly well suited to heavy goods traffic where there is a particular danger of overstepping (for example, if there is a changeover in traffic flows on entry and exit from marker posts and at carriageway and lane changeovers).

The transposable marker posts are made from polythene 1.10 m in length again. Empty, each post weighs 35 kg, filled with water 200 kg. The posts are keyed together in flexible fashion. Installation including filling is carried out at a rate of 600-700 m per night with a team of 5-6 men. This system is intended to replace spot markers, for example cones. It is a continuous system which prevents any voluntary overstepping.

These two types of equipment can be relocated across the width of one lane by a machine at a rate of 5 to 10 km/hour. This enables for example;

- the transport to site, keying together and filling of the marker posts on the hard shoulder without any interference with traffic and then installation at night for example.

- operation of one or more lanes depending on the traffic flow during the day by changing their direction; for example operation of a five line carriageway with three up or three down lanes depending on the time of day.
b) **Marker vehicle**

This is an autonomous vehicle used for the placing, collection and automatic storage of road signaling cones. The storage on the vehicle is 240 cones of 75 cm in height. Placing or collection is carried out at 13 km/hour to the left or right of the vehicle, with the possibility of simultaneous placing on one side and collection on the other with a transfer shift of 3.50 m.

2. **Methodology**

Field engineers are provided with a set of documents giving a very practical explanation of the measures to be taken for operation and marking of sites.

The existing documents are as follows:

- **Temporary marking. Gangers' Manual:**
  - volume 1: ordinary roads
  - volume 2: major roads
  - volume 3: freeways
  - volume 4: urban networks.

- **Site operation:**
  - site chief's handbook
  - road safety and operating group handbook
  - lane changeover - Technical Guide.

CHAPTER 5: equipment and methods for training and informing personnel responsible for maintenance

The basic aids are:

- the preventive maintenance technical guide which provides all the necessary information to engineers responsible for the management of a network for pavement evaluation, definition based on the results of those sections of road where work should be programmed and for formulation of the necessary credit requests.

- a set of documents (recommendations, directives) concerning maintenance techniques in which the fields of use and the conditions of application are defined (production and application of a technique for example). These documents enable the choice of a suitable technique and ensure its correct execution.
These documents are updated whenever necessary. The following also exist as a supplement to these documents:

- for Department of Highway personnel required to monitor maintenance work day by day, sheets known as "ganger sheets" containing the main characteristic of the technique described in detail in the documents quoted above on a card).

- Information Notes for techniques being developed, the aim being to provide Department of Highway Engineers with real information, the risk however being a lack of exhaustiveness or error. 25 Information Notes have appeared already for the field of pavement techniques alone. They are published in batches of 4,500 copies, 3,000 of which are sent directly to Department of Highway Engineers.

- technical advice for proprietary techniques comprising:
  - presentation of the product by the company
  - characteristics measured in laboratory
  - the government circular concerning the utility of the product, its fields of use and state of the art knowledge of its characteristics.

We also note the recent appearance of a Practical Guide to routine pavement maintenance intended for site personnel. Care has been taken in the design of this guide to make it attractive to site personnel. It contains in a suitably designed and pleasing layout:

- general comments on pavements (composition, operation),
- definition of standard deterioration (the photographs used are always the same regardless of the document and the personnel for whom it is intended),
- the materials and pavement techniques used for maintenance,
- finally a dictionary of technical words.

A video cassette of this document is also available.

Overall, there is therefore a concern:

- to provide information as rapidly as possible (updating, information notes),
- to ensure standardization of content regardless of the addressees.
A study was recently carried out in order to assess the impact of these documents (162 engineers - cost 240 000 F) by an outside body specializing in option polls. The results of this survey show that these documents are well perceived.

In parallel with these documents or audio visuals, a training course has been set up for "heads of maintenance", i.e. the road network maintenance departmental head (there are 95 departments in France).
DEVELOPMENT OF MAINTENANCE MANAGEMENT AND CONTROL
SYSTEMS

Lars Bergfalk
Techn. director
National Road Administration
Sweden

1. INTRODUCTION

Road maintenance has during the last two decades become more and more important. It's percentage of the founds to the road authorities is still increasing in most countries. The demands from society represented by government and local authorities, from industry and from road-users are growing. Cost-benefit analyses show a good revenue of better maintenance standard to society as well as privat companies and road-users. However the budgetary restrictions are strong, which means that the road-authorities must have a good control of how they spend the money. They should also be able to show the revenue of every dollar or "krona" spent on roads to recieve the optimum budget level.

Road administrators all over the world therefore need efficient management and control systems. During the last years, development of such systems have been going on in most countries. Very often the planning systems have been given priority, while the control and follow-up systems have been given less interest. An other important part of the management system is collection and treatment of the information upon which the planning is based, such as road and traffic data.

* The article is prepared in cooperation with R Fredriksson, S Tykesson (M. Sc) and K Olsson (B.A), Swedish National Road Administration.
The development and use of pavement management system in Sweden will be presented. Since Sweden is a country with a long winter period, snow and ice control is an important task for the road authorities. As a part of the maintenance control system, studies of the effects on the traffic safety are made. The study of a period from 1972 to 1985 has recently been finished and will be presented.

Finally the new Swedish traffic measurement system will be presented. This system will give information about traffic flow for different types of vehicles, weight of the vehicles and the speed. This information gives us a better base for the planning as well as the control of the maintenance activities.

2. PAVEMENT MANAGEMENT SYSTEMS

Introduction

The term "Pavement Management System (PMS)" came originally into use in the late 1960's and early 1970's when the entire range of activities involved in providing and maintaining pavements became of increasing importance.

At present there is no universally accepted definition of a Pavement Management System. It can involve construction, maintenance, planning, budgeting and ranking of alternative decision possibilities.

A PMS should give an optimal budget and a maintenance plan and also state the future (five to ten years) consequences in technical and economic terms of alternative budgets and maintenance strategies.

Existing management practice

Thirteen OECD Member countries have reported on existing pavement management models.
User costs very rarely appear directly in decisions to intervene but are commonly indirectly considered as a consequence of using surface condition parameters and indexes.

Intervention thresholds and forecast models established for specific pavement parameters are commonly used and/or under study.

The most straightforward optimization approach involves the choice of a directly measurable variable as an objective function.

The fundamental basis is that the road manager makes decisions that affect the road and its function in the transport system.

A PMS should be regarded as an aid in the decision process (to provide the greatest possible benefit of the money invested), and may then be referred to as a "decision system". The task of the decision system is, using data and different models, to describe reality and to illuminate the consequences to road-users and the society of various courses of action, and, thereby, to provide a basis for decisions.

Principally socio-economic evaluations are used in the strategic and tactical subsystems. Financial considerations are taken in the operations subsystem. In other words, the selection of road transport and surface standard should be made on the basis of socio-economic considerations, and the selection of design and method should be based on financial criteria, taking local conditions into account.

Description of the Swedish PMS

The long term maintenance planning has been gradually developed within the framework of 5-year plans (revised every third year) which were introduced in the early seventies. This planning has also gradually developed into an objective oriented planning system.
Measurements of the condition of the road have been used to divide the road network into 3 conditions classes:

1. acceptable standard
2. repair needed
3. immediate repair needed

The classification is done using a weighted point system. The total amount of condition points is based on the components roughness, rut depth and percentage of cracked road surface.

The classification is used on management level to describe the condition of the surfaced roads.

Considering the present condition, the assumed development of this condition and the stipulated standard level projects are selected and ranked in 3 or 5 year regional plans. This work is to a great extent carried out by the regional pavement engineer, whose experience will affect the final ranking and the annual programme decided by the regional road director.

Future Swedish PMS (PUB)

Step 1 deals with indentification and ranking. Data from the Road Data Bank (road data, traffic data, surfacing data and RST-data) will be used to answer questions like where, when and approximate costs.

Step 2 is a method and design phase and in addition to the data used in step 1, data from inspections, FWD and soils surveys, etc will be utilized. A special data bank file, "operations data bank", containing information on design, methods and costs depending on existing construction, main damage type, climate and traffic will be attached to this step.

To enable a fair comparison of potential resurfacing projects the inventories will be based on regionally completed surveys i.e. all roads will be surveyed within a relatively short period of time.
Models for practical use on project level presuppose among other things full knowledge of the road construction. When such data is lacking or unreliable the models are not suitable for practical use at this level.

An alternative to structural deterioration models is to forecast the deterioration and relate it to the road performance. These models predict future roughness and cracking on the road based on previous conditions and experience.

In step 2 more detailed investigations will be carried out to find the causes for failures and damages and to be able to propose repair or rehabilitation method.

In addition there should be possibilities to vary the budget and the repair methods and calculate the future consequences i.e. resulting conditions and future maintenance costs.

When optimizing the surfacing programme the combination of suitable methods, giving the greatest economic return within the actual budget, are selected.

Some regional preparations are needed to make step 1 operational. Existing surfacing data must be supplemented and improved and certain new data will be required.

The GALANT system

GALANT is a Swedish system especially developed for local municipal authorities. Today it is used by some 20 towns of different sizes.

The GALANT system is a tool which permits several tasks related to the planning of operation and maintenance works for road and street networks to be carried out rationally and reliably.
With the help of GALANT, alternative maintenance plans and strategies can be analyzed, utilizing new methods for assessing maintenance requirements.

The information necessary for the production of a sound foundation for the working, planning, and decisions-making processes is stored in a data-base. In addition to a traditional facility register, the data-base includes other combinable registers covering measures, condition, utilization of facilities, and premises for operation and maintenance planning.

GALANT also has processing routines which make it possible to compare alternative maintenance strategies, prepare surfacing plans, analyze changes in condition, and follow-up the effect and cost of the measures adopted.

3. WINTER ROAD MAINTENANCE AND TRAFFIC SAFETY

Because of its geographical position and the long distance from north to south - about 1600 km - different winter road maintenance efforts are to be made in different parts of Sweden.

In the northern parts the winter lasts from October to April with plenty of snow and a severe climate. In the south of Sweden the winter period is much shorter and not so snowy. But instead the temperatures are just over or under 0°C which cause sudden slipperiness.

Important for passability and traffic safety during the winter period is the choice of service and maintenance measures.

This geographical variation causes big variations of the accident risks in the different parts of the country. So is, for example, during the winter the accident rate - or accident risk - about 7 times higher in the south of Sweden compared to the northern part.
The following measures are significant for maintenance operations during the winter:

* snow removal,
* chemical ice control with salt and
* mechanical ice control with for example sand.

The road network in Sweden has been divided into the following four categories in order to serve as a basis for the winter road maintenance efforts.

1. Motorways and 4-lane roads, as well as roads with traffic exceeding 7,000 AADT.
2. Other national roads plus roads with traffic between 1,500 and 7,000 AADT.
3. Other primary and secondary county roads.
4. Tertiary roads.

The Swedish National Road Administration has the responsibility for about 100,000 km roads. About 30% belongs to the road classes 1 and 2 where principally chemical ice control is to be applied. On the road classes 3 and 4 mechanical ice control is used.

Ice control measures are to be taken on high volume roads (class 1 and 2) before morning and evening traffic has started. When necessary preventive de-icing is to be applied.

Normally, on roads in classes 3 and 4 mechanical ice control through spot or track sanding is to be applied. Roads with less traffic than 500 AADT are normally sanded only in case of severe slipperiness. Furthermore, consideration ought to be taken to the special requirements of commercial transport or to other altered traffic conditions on certain roads due to special circumstances e.g. during the tourist season at sport resorts.
Criteria for snow removal (ploughing)

<table>
<thead>
<tr>
<th>Road class</th>
<th>Start criteria snow depth (cm)</th>
<th>Performance time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>3-4</td>
<td>8</td>
<td>5-7</td>
</tr>
</tbody>
</table>

A great deal of attention has to be paid to the traffic safety situation for the unprotected road users, i.e. pedestrians and cyclists.

It is important that the winter maintenance standard on pedestrian and cycle paths is high enough for the unprotected road users so they do not prefer to use the carriageway. Pedestrian and cycle paths used frequently, especially by children and located near schools, hospitals and service institutions are the most important.

The costs for winter road maintenance in 1985 on state roads were about SEK 600 millions or SEK 6000/km. About 50% was spent on snow removal efforts.

Since the beginning of the 1980's the winter road maintenance has been improved in order to increase traffic safety and passability.

Our goal is that increased efforts on winter road maintenance shall diminish the number of accidents, especially on the highly-used roads, with 200 accidents/year in ten years.

Traffic safety study

A recent investigation shows the change in accidents and the effects of winter road maintenance efforts from the beginning of the 1970's until 1985. It has been studied how the percentage of winter accidents of the whole year has changed during the period. As a measured variable the change in the number of single accidents is used.
Single accidents have been chosen on one hand because it is the kind of accident that primarily can be influenced by winter road maintenance efforts, and on the other hand because the change in the number of single accidents follows the change in the traffic volume.

The percentage of single accidents in winter during the 1970's and the beginning of the 1980's has been about 60%.

The increased efforts on the high volume roads in the beginning of the 1980's have given a decrease in the percentage of single accidents in winter to about 57% (1985).
The resources for winter road maintenance on the road classes 3 and 4, where normally just mechanical skid control is used, is lower today than it was in the 1970's. The diagram also shows that on this road network the single accidents in winter have not changed in a positive direction.

Since the traffic volume increases equally in summer and winter the effect in the number of winter accidents can be predicted from the real number of single accidents during the summer.

This model is based on the assumption that the increased accident risk in winter depends on the deteriorated road conditions and subsequently depends on our winter road maintenance activities. Increased efforts for the traffic safety in winter should for the same reason result in an accident reduction.

In this investigation the effect of the winter road maintenance efforts from the 1970's has been calculated by comparing the years 1983-85 with 1972-74.

On the high volume roads where, in addition to snow removal and chemical ice control, also preventive de-icing, "patrol car" and improved supervision is used, there is a reduction of accidents of about 8% corresponding to a diminution of the number of single accidents with 230 acc/year. The reduction of personal injury accidents is about 20% or 200 accidents/year.

On the roads with a low traffic volume where the level of service is lower, the number of single accidents has increased with 2% or about 25 accidents/year. The personal injury accidents were reduced with about 11% but this reduction is considerably lower than the reduction on the highly-used road network.

The results of the study confirm the assumption that the traffic safety on the high volume roads
has been improved through a higher level of service obtained through more efficient maintenance activities at proper time.

The change in personal injury accidents, which is considerably better on the high volume roads, also indicates that the road users do not use this higher service level in a "wrong" way through for example higher speed.

4. TRAFFIC MEASUREMENT SYSTEM

The National Road Administration has regularly monitored and recorded traffic flow since 1953. The parameter used has been axle pairs per annual average daily traffic (AADT).

Applications fields in which traffic data provides invaluable assistance include:
- Comprehensive planning
- Economic planning
- Design
- Maintenance planning
- Selection of maintenance measures
- Road safety
- Research and development

The total length of the roads in the network covered by the traffic measurement system is approximately 100,000 km, of which about 25,000 km consist of national main roads and primary regional roads.

Today's system

The traffic measurement system consists of three separate systems.
1. Permanent system to determine change in traffic flow, i.e. traffic development trends (increase or decrease). It consists of 80 stations chosen in such a way that they are representative for the whole network.

RATE OF TRAFFIC DEVELOPMENT IN %

2. Traffic sensus system

Traffic measurements are carried out throughout 6-years periods. Within a given period, traffic on national main roads and primary regional roads is counted every third and sixth years, while traffic counts on other regional roads are divided among the other four years.
Results are presented both in graphic and tabular form, and consist of traffic flow expressed as AADT. Vehiclekilometres are broken down on regions, road categories, wear course types and traffic trends. All traffic information is presented with known accuracy (95% confidence interval). Periodically issued traffic flow maps are on popular form of report.

The statistical model

The statistical model has been formulated so that - in addition to providing estimates of traffic flow and vehiclekilometres - it permits the uncertainty of these estimates to be calculated and expressed within a 95% confidence interval.

3. Measurement carried out on request for a specific place and time.

Future system

During the last few years there has been an increasingly great demand for information about traffic structure, speed and axle loads on our road network. Because of this ever-increasing demand, a new traffic measurement system with new traffic parameters has been designed.

The new system will be tested during 1987-88 and in full use from January 1989.

A system designed for vehicle detection, vehicle weighing and speed measurement is necessary since requirements are expressed in data concerning traffic structure pertaining to type, weight and speed. Weighing vehicles is a relatively expensive method of monitoring, while classifying and speed measurements can be carried out relatively inexpensively.

Monitoring the development is aimed towards building a number of permanent measurement stations placed throughout the country.
representing different road categories. The stations are located at measurement points where continuous axle pair measurements are currently being taken. All the permanent stations contain equipment for vehicle detection and speed measurements. Some stations are even equipped with vehicle weighing equipment. The compiled data in the stations is automatically transferred to the central computer at the main office via the telecommunications system. The capital investment for a measurement station without weighing equipment is approximately 150,000 SEK and a station with weighing equipment is approximately 450,000 SEK.

In addition to the permanent stations, a lightweight mobile monitoring unit for vehicle detection and speed measurement is being developed. It can be used for taking comprehensive measurements throughout the country's road network, in the same way as the current flexible system for axle pair measurements is taken. Each unit of the new equipment is estimated to cost approximately 20,000 SEK.
The new traffic data will be easily accessible through a database, publications and as input in new management systems as for example the pavement management system.
"HIGHWAY SNOW AND ICE CONTROL - Nordic overview"
Kent Gustafson
Chief Researcher
Swedish Road and Traffic Research Institute

ABSTRACT

Highway snow and ice control in the Scandinavian countries differs to some extent owing to variations in a.o. climate and traffic. A common policy seems although to be a bare pavement on the more heavily used road networks. This is accomplished by chemical deicing with NaCl. On other roads mechanical deicing, ploughing and spreading of abrasives, is used. In the paper standards and criterias, type and extent of the snow and ice control are described.

The consequences of winter road maintenance without salt have been investigated in Sweden and Finland. In the Swedish experiments accident rate, road condition, corrosion and other factors were studied. The research about the advantages and disadvantages of salting are still in progress. An experiment with a whole region free from salt in winter maintenance are underway.

Efforts are made by the road keepers to reduce the use of salt. A few methods and strategies that has been succesfully tested are described. To prewet the salt with a solution has been tested during some winters and the method is successively introduced in winter maintenance practicies in Denmark and Sweden. Ice warning systems have been developed in Sweden and Denmark. Sensor stations connected to central units are in operation and a great part of the main road networks is covered.

Alternatives to NaCl has been studied at VTI in Sweden. The paper describes results from tests (i.e. melting capacity, corrosion, effects on cement concrete) with calcium magnesium acetate, CMA.

Highway snow and ice control by road surface means has been tested by studying the susceptibility to icing of various pavements and the influence of the wearing course on deicing measures. A speciell interest has also been shown to asphalt concrete mixed with rubber granulate or salt pellets. Rubber asphalt and Verglimit have been tested without clear results.

Finally a Swedish R&D-program with the aim of reducing the adverse effects from salt is described. In a number of projects the consequences of reduced salt use, new methods and new strategies will be studied.

1. Introduction

Winter maintenance is one of the most important tasks for the road administrators in the Scandinavian countries due the severe climate in winter time. The demands from society are high regarding traffic safety and traffic flow day and night all the year and necessitate effective snow and ice control measures. Highway snow and ice control differs to some extent owing to variations in a.o. climate and traffic. A common policy seems although to be a bare pavement on the more heavily used road networks. This is accomplished by chemical deicing
with NaCl. The use of salt is a very discussed matter due to the negative effects. Salt increases the speed of corrosion and a Swedish calculation estimate the car corrosion to be appr SEK 5-6 thousand millions per year and appr. SEK 1-2 thousand millions are due to salt spread in winter maintenance. Salt also has an effect on concrete bridges and the environment. The relationship between chemical deicing and traffic safety has been investigated but is still uncertain and sometimes questioned. Studies with the aim of clarifying this relationship are in progress in Sweden.

Because of the side effects from salting efforts are made by the road keepers to reduce the use of salt. In the paper two methods to save salt are described. Tests with prewetted salt have shown to be effective and the method is successively introduced in winter maintenance practicies esp. in Denmark and Sweden. Ice warning systems have been developed as a tool for the road administrator to have more reliable informations for his decisions in winter maintenance. The systems in the different countries are similar and one is described in more detail.

Another way of reducing the use of NaCl could be the use of an alternative which is effective and economic but doesn't have any adverse effects. Some results from the studies with CMA, Calcium Magnesium Acetate, are described. Finally an extensive R&D-program with the aim of reducing the adverse effects from salt is shown. In the Swedish "Minsalt-program" a number of projects will study the consequences of reduced salt use, new methods and new strategies.

2. Standards and criterias

Snow removal: Some kind of standard have been worked out in the Scandinavian countries, except for Denmark. In practice the removal of snow in Denmark starts when the snow depth is between 3 and 5 cm. Any total time of performance duration has neither been set out but as a point mark the time of appearance by maintenance personnel should not exceed 30 minutes.

In the other countries the principles of standard are very similar. The road network is divided into priority classes, three in Finland and four in Norway and Sweden. Depending on class of road a starting criteria of snow depth and a time of performance duration are set out. The criterias are similar and for instance varies the snow depth between 2 and 5 cm and the time of duration between 2 and 4 hours in the Norwegian standard. The main goal is that the roads should be trafficable to vehicles with normal winter driving equipment. In very extreme weather situations this cannot be fulfilled and sometimes there can be roads or road sections that must be closed because of safety reasons, but this is very seldom. In the Swedish standard there is some tolerance in the starting criteria depending on traffic, type of snow and the snow plough plans.

The snow removal of pedestrian and bicycle paths has got more attention the last years because a.o the fact that a lot of accidents happen on these paths by slipping, tripping or collisions. In Sweden the paths are maintained with respect to traffic safety and driving condi-
tions to the unprotected road users. The standard is said to be such that cyclists and pedestrians would not be tempted to use the road-way. In Denmark the aim, esp. in the cities, is to have the bicycle paths cleared before the traffic to schools.

Chemical deicing: The standard and criteria for salting varies to some extent between the different countries. Salt is most widely used in Denmark and Sweden and not as much in Finland and Norway. In Denmark salting is performed on all state and county roads. The aim is to prevent snow and ice sticking to the surface by preventive actions. The time between call out and the finished measure is aimed at maximum 4 hours.

In Sweden salting is performed mainly on the roads with an ADT (Average Daily Traffic) of more than 1500 vehicles. In the standard criterias regarding time of action and total time (between ice formation and finished deicing measure) are set out. Roads with ADT between 800 and 1500 vehicles are salted only during the initial period with icy conditions in the autumn when conditions are unexpected to the drivers. Roads with an ADT of less than 800 vehicles receive only mechanical deicing. The aim with salting is to have a bare pavement and to accomplish this the removal of slush is essential.

Salt is used mainly for preventive actions which means the prevention of the bonding between snow and ice and the surface. This requires only small salt application rates and these varies between 5 and 25 g/m². The melting action is minor and ploughing is therefore necessary. Salt is used in the temperature range 0–6°C. NaCl is used almost exclusively, but in Norway some CaCl₂ is used in solution when using the prewetting method.

The total use of salt in winter maintenance in Sweden is appr. 300 000 tons per winter. Approximately the same amount is spread in Denmark, while the two other countries are spreading less. The use on the state roads in Finland is appr. 75 000 tons and in Norway only 20 000 tons.

3. Studies of different deicing strategy on salted roads

Both earlier studies and current research into chemical deicing show that negative effects (e.g. the environment, corrosion, bridge constructions) as well as positive effects (road safety, trafficability) are obtained. However, the effects of salting, mainly with regard to traffic safety, have been difficult to quantify. In Finland during the 1970's tests were made with winter maintenance without salt on certain main roads in southern Finland. The tests met with massive resistance from road users, primarily representatives of heavy vehicle operators, and especially during the latter test winter. This led to the tests with unsalted roads being abandoned after only three months, a fact that is considered as demonstrating the necessity of salt on the main roads.

A series of studies to determine the consequences of winter road maintenance without salt was also carried out in Sweden in the early 1980's. In one county four roads were kept unsalted a few winters and
a.o. the following variables were studied: accidents, road conditions, skid resistance, speed adaption, corrosion, dirt spray, drivers' attitudes. The experience and results of the studies showed that salting is a very complex problem. Many different impacts are involved some of which are very great. The largest relative effect is on number of accidents and corrosion. A cost calculation were made and showed that the two large factors when abandoning salt are the increased number of accidents and the reduced corrosion to car bodies. The two costs were of the same magnitude. Other effects were calculated to be much smaller. There were also effects which were very difficult to measure, but which nevertheless are significant. Examples include truck drivers' demands for a safe working environment and the doubts of road maintenance personnel regarding a different approach which, in fact, means lower winter road surface standard.

Experiments with unsalted roads are still in progress in Sweden. An experiment with a whole region free from salt started in the winter 1985/86. The aim of the study is to clarify the consequences to the drivers, environment and the road keeper when a whole region is free from salt. In the winter 1986/87 salt was abonded on the island Gotland in the Baltic Sea. The choice of Gotland was made because this is a small region, it's very limited and the exchange of cars to the mainland is minor in wintertime. The studies will primarily include the following: Road conditions, corrosion, traffic safety, environment, attitudes.

Parallel to the studies on Gotland other experiments with unsalted roads will be carried out. In one project the consequences when abandoning salt on a highway in the northern part of Sweden will be studied. In another test the road network that is salted in a county is drastically reduced. The reduction will be from 1500 km to 400 km salted roads. Snow and ice control will be performed only with abrasives and by ploughing.

4. Ways to reduce the use of salt

4.1. Prewetted salt

In order for salt, such as NaCl to start melting snow and ice it must be in solution. When spreading dry salt, a certain time always elapses before the salt begins to act on the road surface, since a salt solution must first be formed. This time can be reduced by adding the moisture before spreading takes place. The moisture added to the salt may be water alone or a suitable chemical solution such as NaCl or CaCl₂ solution. The dry salt is prewetted so that a thin film of solution covers the particles and the melting effect starts very rapidly. When spreading dry salt a relatively large part is scattered or blown off the road by traffic before it has had time to act.
By prewetting the salt adhesion to the road surface is improved and only a small part blows away. Prewetting also makes the spreading pattern more homogeneous. A smaller quantity of prewetted salt can be spread to achieve the same level of maintenance as with dry salt. The method of prewetted salt has been tested in Sweden for four winters since the winter 1980-1981. The method has also been tested, but to a minor extent, in the other Scandinavian countries and its use is now increasing.

Prewetting of the salt can principally be carried out in two ways. The solution can be sprayed on top of the salt in connection with loading the truck. The other way, and the way used in Scandinavia, is to prewet during saltspreading. The saltspreader are generally made of:

- a conventional spreader with its distribution system; - one or two tanks, glassfiber or metal, usually about 2 m³ for the storage of the brine and with a prewetting system (nozzles, pump, electronic equipment).

Depending on the various models, the prewetting of the salt can be performed:

- on screw-machines, in the exit tunnel of the screw or on the spinner plate
- on belt-machines, either along the belt or at the end of the belt.

The spreaders give a homogeneous mixture and more or less sophisticated electronic equipment ensures that the proportion of solution to dry salt is maintained at the correct level. Common is 20-30 % of solution to the dry weight and at the same time a reduction of the dry salt by 30 %. This means an actual reduction, saving on salt with about 20 %.

The equipment for mixing the brine varies between and in the Scandinavian countries. All the range from very simple and inexpensive equipment to very much advanced, costsome and fully automatic mixing constructions have been developed. For road purposes NaCl- and CaCl₂-solution has been tested, but today NaCl is used almost exclusively. In the Swedish tests little or no noticeable difference with regard to effectiveness was found between the two solutions in the temperature range (0 - -7°C) where salting is performed. This together with the fact that CaCl₂ has a chemical effect on cement concrete has made the use of CaCl₂ very restricted.

The Swedish trials showed that a reduction in salt could be made with wet salt spreading and at the same time having the same or better effect of the salt. The spreaders used had an automatic reduction of dry salt by 30 % by weight. Since a great part of the solution is water the actual reduction of salt is about 20 %. During the trials the effectiveness of the method was followed by measurements of the skid resistance. In many cases a more rapid melting effect and faster increase in the coefficient of friction could be monitored on sections with prewetted salt. This was especially pronounced on "hard" surface conditions such as hoarfrost and black ice.
The experiences from the tests with prewetted salt shows these advantages and disadvantages.

Advantages

- Prewetted salt adhere better to the road surface which means a more homogeneous spreading pattern and less wastage outside the road.
- Faster melting reaction.
- Can be used at somewhat lower temperatures, with NaCl-solution down to app. -10°C.
- Prewetted salt create better conditions for preventive applications.
- Less salt can be spread to maintain the desired road standard which will mean less negative effects from the chemical use.
- The salting can be performed at higher speed.

Disadvantages

- More investments in spreaders and equipment for making the brine.
- The equipment is more complex.

4.2 Road weather information system

Very intensive research is presently pursued in all the Scandinavian countries on ice warning systems or road weather information systems. A reliable system giving information of winter road conditions and predicting slippery conditions is important to the road administrator in his task to improve the winter maintenance and thus traffic safety and driving conditions. The time and phases of development of warning systems in the different countries have varied. The Swedish Road Administration has since more than ten years worked together with research institutes, universities and Swedish industry in the development of an information system. Similar to this is the work carried out in Finland, which has also led to a commercially available system. Sweden and Finland have actively participated in the European technical program EUČO-COST 30 theme 8 dealing with the development of an automatic system for observing, forecasting and warning of adverse road conditions. In Denmark the first steps were taken about five years ago when six systems on the market were tested. Based on the results requirements of a system were specified and a Danish company were selected for the delivery.

The purpose of an ice warning system is to give the local road keeper detailed information about the weather and the road conditions in his district. The information will give indications if there is a risk for slippery conditions and will allow the snow and ice control measures to be started at the right time.
In the following the Swedish road weather information system (VVIS) is described in more detail. The systems in the other Scandinavian countries are in many ways similar to this. The VVIS system consists of a central unit and a number of field stations. The field stations are situated at road sections where icy conditions are likely to appear most unexpected and frequent. To identify the hazardous spots and to ensure the best possible siting of the stations a climate mapping of roads is carried out. The survey is primarily performed with specially equipped measuring cars, which register air and road surface temperatures, air humidity etc. The central unit of the system usually handles data from 20-40 field stations and covers the area of one county. The central unit consists of a computer with connected equipment like speech synthesizer, screen, printer etc. The results are transmitted by the telephone network and also automatically to the Swedish Datavision network.

The field station are equipped with sensors for determining the air and road surface temperature, and air humidity. Some of the stations also have sensors for wind speed and direction. New sensors for road surface conditions and precipitation are under development. The central unit scans the field stations every half hour. By phone the current values can be reached together with calculated values of trends and dewpoint temperatures. The central unit can also be programmed to give warnings according to selected functions and if requested make a call to the foreman on duty.

The winter 1985/86 there were 11 central units and appr. 250 field stations in operation. The plans for the system is to cover the most important roads in Sweden and to have appr. 20 centres and 500 field stations when the system is built out.

The VVIS system has been continuously improved and most roadmasters can get the information from the central units by speech synthesizer and printer. A test with videotex terminals connected to the Swedish Datavision network has been very successful and today the information thus can be available both at the local maintenance base or at home. A new generation of field stations are also coming into service with more computer power and digital data communication. The presentation of information from the system can be made more intelligent and easier to handle.

Research is steadily in progress to improve the operation, accessibility and reliability of the system and to increase the use of the system. One important area of research is to develop sensors detecting the road conditions and the type and amount of precipitation, esp snow. In order to install a surface condition sensor at every field station these have to be rather cheap and reliable. A new road surface sensor has been developed by a Finnish manufacturer. In Denmark a sensor measuring the surface resistance is tested and in Sweden the development of surface condition sensors is in progress. A special testing station has been in use for several years. Different types of sensors are tested before they are accepted and put into operation in the field stations. The testing station is also used for research purposes.
Under discussion is also to make the information from the system more available to the public. Drivers could be informed through different medias (e.g. radio, TV) as well as by direct visual information of temperatures, road conditions etc on displays at gas stations, parking lots etc.

5. Alternatives to sodium chloride

The negative effects from road salt have led to intensive efforts being made to find alternative chemicals which are non-corrosive or non-damaging to the environment while being suitable for winter road maintenance from cost and efficiency aspect. The list of chemicals tested can be made very long but there are only very few ones that have been used to any extent.

Calcium chloride, CaCl₂, has earlier been used, esp. at lower temperatures, but the use is now very restricted. In summertime although CaCl₂ is still in use for dust prevention on gravel roads. CaCl₂ can be effective at lower temperatures and it melts snow and ice more rapidly than road salt, but the side effects are as serious or even worse than for sodium chloride. It's hygroscopic, which tends to keep the road surface wet longer, corrosive and affects the environment negative. The principal reasons for not using CaCl₂ is however the higher direct cost and the negative impact on concrete structures. Urea, CO(NH₂)₂, are widely used on airports because it's less corrosive than sodium chloride. Urea has been tested on roads, although only on very short sections, such as bridges, as early as in the 1960's. It was found that urea is less effective than road salt, it could in practice only be used at temperatures above about -3°C and it requires twice as much urea as sodium chloride for the same deicing effect. The use of urea on roads is therefore very restricted and only a few hundred tons are spread per winter.

The most recent and thorough study of alternatives, made in USA in the late 1970's, identified calcium magnesium acetate (CMA) as a potential deicer for roads and airports. In Sweden and at VTI CMA has been tested intensively for some years. CMA obtained from acetic acid and dolomitic limestone has been investigated primarily in laboratory but a field test with 50 tons has also been carried out.

The investigations carried out so far in Sweden is:

1) Deicing effect in laboratory.
2) Corrosion to steel, aluminium and magnesium.
3) Effect on cement concrete.
4) Field test.

Deicing effect of CMA

The freezing point depression of CMA varies between app. -10°C and -28°C depending a.o. on the Ca/Mg ratio, compared to -21,1°C for NaCl. The melting effect however varies less depending on the ratio and more on the grain size, density, hydration etc. Pelletized CMA has in the tests shown to be less effective than road salt but compared to
urea it's melting capacity is better. In general CMA can be used in the same temperature range as road salt but it doesn't melt ice and snow as rapidly.

**Corrosion to steel, aluminium and magnesium**

Corrosion tests with CMA on car body steel showed that CMA is much less corrosive than NaCl and CaCl\(_2\), see figure 1. The weight loss on steel plates, which were covered with a mix of mud and the deicer for 100 days where after the test period considerable less for CMA compared to the other deicing chemicals in the test. Immersion test with aluminium plates also showed promising results for CMA, which were less corroding than NaCl, CaCl\(_2\) and urea. The difference in speed of corrosion was however not so marked as with steel.

The corroding effect of CMA on magnesium alloy plates has also been tested, while magnesium alloy sometimes can be used in aircrafts. The immersion test compared CMA with Urea and showed that CMA was the most corrosive of the two deicers. The result indicate that to avoid the corrosive effect some kind of surface treatment of the magnesium metal must be accomplished or a corrosion inhibitor be mixed with the CMA.

**Effect on cement concrete**

The effect of CMA on cement concrete has been investigated in some different ways. Standard freeze/thaw tests, an immersion test to see the chemical effect, both in laboratory, and a more practical field test have been carried out.

The freeze/thaw test comprised CMA solution of different concentrations 3-25 % by weight, NaCl, CaCl\(_2\) and MgCl\(_2\) all 3 % by weight in concentration. The result is summerized in figure 2. The trends for the chloride salts, which were only tested for one concentration, have been drawn from the report by Verbeck & Klieger, 1957. According to the tests chloride salts, esp. NaCl and CaCl\(_2\), have a marked peak in scaling by app. 3 % concentration. The scaling effect then decreases for sodium chloride while it increases very much for calcium and magnesium chloride with higher concentration. The scaling from CMA are somewhat different from the chloride salts. CMA has no similar peak but has a linear increase in scaling with concentration to the same maximum level as for NaCl. This can mean that if a concentrated oversaturated solution is induced in the concrete, in cracks etc, due to the evaporation of "salted" water the scaling effect can be severe.

Cement concrete can also be affected chemically by deicing agents. This chemical effect has been studied in a test at Lund Technical University, Sweden. The immersion test with specimens in saturated CMA, CA, NaCl and CaCl\(_2\) solutions ran for more than a year. The specimens in NaCl-solution were very little damaged, while the effect on the cement concrete in CMA was considerable. Some of the specimens had more or less fallen apart, esp the "poor quality" cement concrete in saturated solution at +20°C. Samples in CaCl\(_2\) solution were also heavily damaged and perhaps even faster than with CMA.
These described tests are under laboratory conditions and the question is how the results can be transferred into the field. To get more information about this a more "realistic" field test is running at VTI. Cement concrete cubes of different quality are exposed under field conditions since about one year. During the winter the samples were sprayed with deicers every day when weather conditions permitted salting. After one winter the specimens sprayed with chloride salts were damaged. The poor quality concrete sprayed with NaCl had the largest weight loss, while the high quality air-entrained cement concrete was nearly unaffected by the deicing chemicals. All the samples sprayed with CMA solution were intact after this first winter. The result indicates besides the minor effect from CMA, that the quality of the concrete is essential for the salt resistance and explains the need for air-entrained concrete under these climatic conditions.

Field test

During the winter 1984/85 the Swedish Road Administration performed a preliminary field test with 50 tons of CMA. The CMA was very fine grained with low density and the material was at that time not enough developed for road purposes. The field trials showed that CMA could be used as a deicer but it was not as effective as road salt. Some handling and spreading problems occured with the light material.

Summary CMA

The CMA research has led to these findings and conclusions:

- CMA can be used in the same temperature range as salt, but more CMA is needed for the same melting effect. CMA does not melt ice and compacted snow as rapidly as salt.

- CMA are much less corrosive to car body steel and aluminium than other used deicing salts. It is more corrosive to magnesium alloy than urea.

- The effect on concrete is complex. The scaling effect from weak solutions of CMA are less than from sodium or calcium chloride. CMA can however have a chemical effect, but the extent of this is not yet clarified.

- From literature one can find that CMA are less harmful to the environment than chloride salts and that the prize will remain high (about 10 to 20 times the salt price) even with a full scale production.

After some years with interest in CMA, esp. in Sweden, the intensity in research efforts now is lesser. The reason for this is primarily the price picture and the questions concerning the effect on concrete. The tests of CMA on concrete will continue. The road keepers wait and see what will happen commercially and what comes out of the research in USA.
6. **Wearing courses**

The skid resistance of different wearing courses under summer conditions are relatively well known. The variation of the coefficient of friction with speed on dry or wet surfaces has been documented in many reports. The frictional characteristics of different surfaces in winter time has however not been studied to the same extent. The interest in winter skid resistance has been low also in the Scandinavian countries. One reason to this is the extensive use of studded tyres in Finland, Norway and Sweden. The use of studded tyres has both directly and indirectly led to relatively good skid resistance values of pavement surfaces. The use of studded tyres does also however create great problems due to the pavement wear. Especially on the heavily trafficked roads the rutting is serious regarding wet skid resistance because of the water that can be standing in the ruts. A lot of research work is carried out to find wearing courses which are resistant to pavement wear. The development of improved wearing courses by studying different pavement types, aggregates binders (modified) etc are continuously in progress.

With the aim of studying the frictional characteristics of different wearing courses in various winter conditions an investigation has been carried out by the VTI during the last winters. The following types of surfaces have been included: dense and open-graded asphalt, single and double surface dressings and special types such as rubber asphalt, Verglimit and Delugrip. One special interest was to study if there is a relationship between texture depth and the susceptibility to icing.

The texture of the surface-dressed sections differed owing to age and wear. In general, the measurements showed that a coarse texture is in many cases positive from the aspect of slipperiness in wintertime. This was particularly noticeable when the surface dressings were new and coarse. However, the positive effect diminished with increasing smoothness of texture and the characteristics were similar to dense graded asphalt.

Owing to its open structure, open graded or drain asphalt generally offers good friction properties in summer conditions, especially in rainy weather. However, the behaviour of drain asphalt, which is very often chosen because of its numerous positive properties, is a very discussed subject with regard to winter maintenance. Problems in wintertime have been noted by road keepers and some of the behaviour have been documented in the mentioned study. In general, the open graded asphalt shows a somewhat greater susceptibility to hoar frost and icy conditions early in winter because of its open structure that influence the surface temperature to be somewhat lower than on a dense asphalt. Also in connection with snowfall the behaviour of porous asphalt differs from the dense types. The porosity tends to keep the snow easier to the surface and cover the road with a slippery snow layer earlier than on a dense surface. Snow and ice also tends to stay longer on the drain asphalt. On salted roads the actions doesn't have the same effect on open and dense asphalt. Many times the salting on a porous surface layer has an effect that disappears more rapidly because once the salt solution is formed on the surface this can be drained out to the road sides. If the snowfall continues there is no salt at the surface and the snow can stick to it and be compacted. On a dense surface on the
contrary, the salt solution remains longer and the deicing effect therefore is lasting a longer time. This means that the drain asphalt sometimes requires more salt and more frequently salting. This behavior of the pervious macadam layers is most pronounced on roads with lower traffic.

Studies of special wearing courses less susceptible to icing so called "ice repellant surfaces" have been carried out in Denmark, Norway and Sweden. Rubber asphalt, with rubber particles and Verglimit, with salt pellets, have been investigated. In Denmark the experience with Verglimit is mostly positive and this surface layer is often considered on so called "white spots", road sections prone to icing. In Norway trials show that Verglimit can have an effect in areas with many temperature changes around 0°C. Trials, with rubber asphalt, Rubit have been positive, but a problem with increased wear from studded tyres has been noted. In Sweden studies with these special surfaces have been performed for many years, but no clear conclusions have been drawn. Various results regarding slipperiness, wear and economy has been noted. A special field test has started this year 1987 with the aim of studying the effect of rubber asphalt and Verglimit compared to conventional asphalt concrete. Three test sections, 1 km each, have been laid and the investigations will include skid resistance in winter conditions, wear and economy. The study will be performed during two to three years.

7. **The Swedish "Minsalt" research programme**

During 1986 a 5—year research programme called "Minsalt", which stands for minimize the negative effects of salt without detracting from traffic safety and trafficability, was started. The Ministry of Communications initiated the wide programme worked out by the Swedish Road Administration in cooperation with the VTI. Since chemical deicing is not only a question to the state roads the municipal road authorities also take an interested part in the programme. The proposed programme was discussed with the other Scandinavian countries, who were interested in the research area and will take active part in a few certain subprojects. One such project investigates what the effects will be when salting in a small number of urban areas is reduced to cover only exposed sections of streets and roads, as well as junctions.

The "Minsalt" programme consists of a number of projects that are more or less comprehensive in their nature. Some projects were already in progress and some others were started in connection with the 5-year programme. The different projects are financed principally by the Road Administration and the VTI. There are also some other financial sources. The programme budget is SEK 7-8 million per year and a total budget of appr. SEK 40 million.

The "Minsalt"-programme is divided into three parts and the following projects are included into these.

A. **Expansion of salt-free regions**

An expansion of the regions or parts of regions where salt is not used in winter maintenance will be investigated. Snow and ice control will be
performed only with abrasives and by snow ploughing. The aim of the projects is to make a comparison of accidents, road conditions, dirt spray, corrosion, environment, road user opinion etc between chemical and mechanical deicing.

In one project a whole region, the island of Gotland in the Baltic Sea, will be free from salt in winter maintenance. The winter 1986/87 was the first winter without salt. In another project a reduction of the salted road network will be studied. This covers one county and in the winter 1987/88 only 400 km of roads will be salted compared to 1500 km earlier. Only the heavily trafficked roads will be salted. Studies in urban areas will also be carried out under this part of the programme.

B. New deicing methods

The objective of the projects under this title is to reduce the amount of salt spread in wintertime. This can be achieved through the development of new and better snow and ice control techniques and to replace the salt with an alternative chemical or with abrasives such as sand, slag or crushed material. The research is divided into four parts:

- Alternative chemical deicing. Calcium magnesium acetate (CMA) has been studied for some years in laboratory and field. A comparison between NaCl and CMA is made regarding their characteristics a.o. deicing effect, corrosion to metals and impact on cement concrete.

- Alternative mechanical deicing methods. The aim of this project is to compare different alternative mechanical methods such as limestone products, slag, crushed stone material and heated abrasives with sand mixed with salt. The interest is focused on skid resistance after spreading, the duration of the measure, costs etc.

- More efficient methods of snow and ice removal. Mechanical and thermal methods including millers, thinner cutters and cutters with studs or rotating knives are studied.

- More efficient use of salt. The aim is to reduce the salt spread with the aid of improved equipment and with better knowledge of optimum application rates. Prewetted salt has been investigated and found to be positive. Another study is the determination of application rates depending on salt grain size, weather, traffic, wearing course etc.

C. New deicing strategies

- Spot measures. Studies will be carried out to investigate the consequences if chemical deicing is performed more selectively only at critical spots and if spots prone to icing are resurfaced with so called "anti-skid wearing courses". A very extensive field test has started where rubber asphalt and Verglimit will be compared to a conventional dense graded asphalt concrete regarding winter skid resistance and wear.
- Weather forecasts and systems for providing information on road conditions. The research in ice warning systems that started more than ten years ago will continue.

- Education. The aim is to intensify and to improve the education in road climatology, deicing methods, equipment etc.

- Preventive salting. The effects of preventive actions on road conditions, trafficability, accidents and salt consumption will be studied.

8. Danish White Spot Program

The Road Directorate in Denmark has started a number of measures to improve winter maintenance on the primary road network. The activities are called the "white spot program", taking it's name from the phenomenon of short road sections prone to early and unexpected icy conditions. Examples of such sections are bridges, rock cuts and sections exposed to cold air drainage. The aim of the program is to improve the economy and effectiveness of snow and ice control by spreading the right amount of salt at the right time and to increase traffic safety in general by eliminating unexpected icy conditions.

The methods used to achieve these goals are

- Monitoring system to detect road sections prone to icing.

- Road weather information system to detect and to give a forecast of the formation of icy conditions.

- More effective snow and ice control by preventive salting and using prewetted salt.

- Using special wearing courses like Verglimit and rubber asphalt.

Detection of white spots: Identification of road sections as white spots can be done on basis of experience by the local road keeper or from accident analysis (compare black spot). The most objective measure is however to make an inventory by a monitoring car. A special car for this purpose has been developed in Sweden. By surface and air temperature measurements together with humidity recordings an identification of sections prone to low surface temperatures and ice formation can be made.

Ice warning system: The introduction of an ice warning system began in the early 1980's. Some commercially available systems were tested but none satisfied all the requirements set up. A Danish ice warning system was therefore developed based on a central personal computer (PC) monitoring road and air temperature, air humidity and road conditions (by surface resistance) at sensorstations in the field. Graphical presentations and prognosis can be made on the central unit PC screen or connected portable PC's which can be used at home by the foreman on duty. The field stations are set out on basis of located white spots. The expansion and development of the system continues.
Preventive salting and prewetted salt: With ice warning system spreading of salt can be carried out early under icy conditions or as a preventive measure already before the icing occurs. Salt can in this way be saved while the application rate can be lower to prevent ice formation instead of melting ice, black ice, hoarfrost etc that has already formed. A small amount of salt on the road surface in the beginning of a snow fall prevents the snow sticking to the surface, helps the snow clearing and saves salt compared to melting the compacted snow afterwards. Another way to reduce the salt application rate and to make the salting more effective is by using prewetted salt. The wet salt method has been tested the last winters and due to the advantages found the method is now introduced.

Special wearing courses: Another way of reducing the icy conditions at "white spots" is to make resurfacing with special wearing courses that are not so prone to icing as conventional asphalt concrete. Rubber asphalt or Verglimit, asphalt concrete mixed with salt, can be used. The Road Directorate has good experience from Verglimit and the laying of Verglimit at "white spots" has been incorporated in the Danish PM (Pavement Management) system. This means that when a resurfacing is decided, one takes into consideration if the road or section of the road is a "white spot" and if necessary, Verglimit is used.
Fig. 1. Corrosion test according to Swedish standard SS 186039. Weight loss in mg/cm² on steel after 100 days.
Fig. 2. Concrete-Frost Testing acc. SS 137236. Tests with 3% solutions of NaCl, CaCl₂, MgCl₂, and 3-25% solutions of CMA. Weight loss after 56 cycles. Trends for NaCl, CaCl₂ and MgCl₂ acc to Verbeck & Klieger, 1957.
Abstract

Research plans for the concrete bridge component protection and the cement and concrete areas of the Strategic Highway Research Program are outlined. Bridge component protection research will be performed through four projects: the assessment of physical condition of bridge components, electrochemical and non-electrochemical methods of protection, and development of a decision model for selecting the optimum protection treatment. Research in the cement and concrete area will be pursued by five projects dealing with the concrete microstructure, alkali-aggregate reactivity, freeze-thaw durability, non-destructive testing, and an expert system for durability diagnostics of concrete.

Introduction

The five-year Strategic Highway Research Program (SHRP) is perhaps the most comprehensive highway research program undertaken in the United States, and is designed to focus on a few but critical areas concerning pavements and bridges. This paper outlines research plans for two of these areas, one relating to concrete bridge components and the other to cement and concrete materials. These two areas, originally proposed separately in the SHRP Research Plans (Final Report, May 1986) have now been grouped under Concrete and Structures. While this was done primarily for management considerations, it also appears logical as the activities in these two areas are closely related and would involve a rather high degree of interaction and coordination.

The need for research relevant to the highway industry in these two areas cannot be over-emphasized. Bridges built in the United States during the post-World War II period have deteriorated rapidly. The principal causes for this premature deterioration are the use of salt during winter maintenance operations and the exposure to marine environments. In economic terms, the problem is of enormous proportions. It is estimated that about 50 billions in current dollars will be needed to repair or replace the prematurely deteriorated bridges on the nation's highways. Saving these thousands of bridges is, therefore, an extraordinary challenge.

The highway industry consumes about 16% of the portland cement used for construction in the United States, representing a capital outlay running to more than one billion dollars annually. Over 85,000 miles of roads and streets are paved with portland cement concrete which is also the most commonly used material for curbs, sidewalks and median dividers. Over 60% of the short-span bridges currently being built in the United States are constructed of concrete. Almost all bridge decks are made of concrete, as are piers and abutments even when steel is used for
the superstructure. Despite the widespread use of concrete, problems regarding its performance and durability remain unsolved. The setting and hardening process of portland cement are still not fully understood, not are the effects of environmental factors on the durability of concrete. Changes in concrete practice and technology have necessitated the need for better specifications and test methods for concrete-making materials.

**Bridge Component Protection Research**

The overall objectives of bridge component protection research of SHRP are to provide methods to protect salt-contaminated concrete from deterioration, and to protect those components which are already exhibiting corrosion-induced distress. These objectives will be addressed through four projects, outlined below, totalling about 10 million dollars over a period of 5 years.

1. **Assessment of Physical Condition of Concrete Structures**

   The task of protecting and rehabilitating existing bridges logically begins with the assessment of their physical condition. Although a number of methods can be suggested for their inspection and assessment, there are serious limitations in terms of speed, reliability and the significance of the results of many of the existing procedures. The greatest single need is the development of a field procedure for measuring the rate of corrosion (as opposed to the presence or absence of corrosion) of reinforcing steel. Other specific deficiencies and limitations of existing methods include determining the permeability of concrete, delamination in concrete beams and substructure components, the condition of slabs under bituminous surfacing, and the effectiveness of membranes and sealer materials. This project will address these needs and deficiencies and develop the most promising solutions into field-proven test procedures.

2. **Electrochemical Methods for Protection and Rehabilitation of Bridge Components**

   The corrosion of reinforcing steel due to chloride from deicing chemicals or sea water is a serious problem for highway concrete structures located in, or exposed to, adverse environments. In recent years, electrochemical methods have shown significant promise of reducing or totally stopping the chloride-induced corrosion. However, despite this promise and potential, a number of problems remain. The electrochemical method of chloride removal may result in increased porosity and permeability of concrete, reduction in bond between cement paste and steel, migration of ions other than chlorides, development of elevated temperatures in concrete, and, if inert electrodes are used, generation of chlorine gas at the concrete surface. Similarly, for the technique of cathodic protection, implementation criteria and long-term effects are yet to be established. Other drawbacks of cathodic protection include its rather high cost and the lack of familiarity within the highway industry with the technique. Clearly these problems need to be solved before routine operational electrochemical procedures for the protection of concrete components can be developed.
3. Methods other than Electrochemical for Protection and Rehabilitation of Bridge Components

Almost always, as circumstances and situation will warrant, conventional approaches either alone or in combination with electrochemical methods would still be used for the protection and rehabilitation of bridge components. The problems associated with presently used conventional approaches are their high cost (largely because of high cost of concrete removal), unknown service life (because of their inability to stop corrosion), long construction times, and the fact that only a few options exist for components other than bridge decks. This research plan is designed to address these problems, to identify less costly but more effective methods of concrete removal, and to develop better options applicable to decks, beams and substructure components.

4. Decision Model

This task is designed to bring together the products of the studies already described to develop a decision model applicable at the project level as opposed to the network level. Such a model will lead to selection of the protection strategy which result in the lowest anticipated life cycle costs for a specified bridge based upon its existing condition and the consideration of options for protecting its various components against damage.

Cement and Concrete Research

The primary goal of SHRP cement and concrete research is to gain better understanding of cement hydration, mechanical and physical properties of concrete, and concrete performance in highway environments. This research is expected to develop the means necessary to improve durability and to increase the service life of concrete pavement and structures. These objectives will be addressed through the following projects totalling about 12 million dollars over a period of 5 years.

1. Concrete Microstructure

This study, while fundamental in nature, has the objectives of developing recommended test methods, specifications, and criteria for concrete with vastly improved performance properties. It will investigate, in a very practical and coordinated manner, the factors controlling cement hydration and microstructure development, and the effect of chemical and pozzolanic admixtures, and will address the question of how the cement microstructure controls concrete performance and how it can be optimized to improve concrete performance. Practical problems with concrete such as early or retarded setting, excessive bleeding, drying shrinkage, permeability, frost damage and inadequate strength would be
stressed in relation to microstructural development, including pore structure. The information and data generated will be synthesized into predictive models along with recommendations for tests and specifications for a superior concrete.

A further task will develop concrete of designed microstructure for highways so that desirable properties will be achieved rapidly and will result in greatly extended service life. This task will use predictive models to select and test the most promising material combinations and processes for improving the microstructure. If successful, it will be further optimized for several aggregate types. The overall study is expected to establish criteria and recommendations for changes required to introduce new concrete technology with emphasis on pavement applications.

2. Eliminating or Minimizing Alkali-Aggregate Reactivity in Concrete

This study deals with concrete deterioration due to alkali-aggregate reaction, and although substantially basic, it is aimed at developing reliable test methods for determining aggregate reactivity and at means to eliminate or minimize deleterious reactions in concrete in both new and existing pavements and structures. In spite of much research, considerable controversy persists over the validity of test procedures and their results even for relatively simple reactive aggregates. Further, environmental conditions promoting the reaction, and pozzolanic requirements to avoid or minimize it, have not been adequately defined. This study will address all these issues. It will establish quantitative relationships among alkalies, aggregate characteristics, and pozzolans that sustain or prevent deleterious reactions. It will also define internal relative humidity and temperature relationships under which expansion occurs. Using this information, practical measures to control expansive reactivity will be identified and reliable test methods developed. The results will also establish guidelines on permissible or required cement alkali-aggregate-environmental combinations to avoid distress due to alkali-aggregate reactivity.

3. Freeze-Thaw Durability of Concrete

Previous research on the mechanism of frost action on hardened concrete has established the protective effect of entrained air. However, recurrent problems of deterioration even with a good quality concrete suggest that our understanding of the mechanism is still inadequate. This study will investigate, in a very systematic manner, the effect of frost action on hydrated cement and aggregates and the protective effect of entrained air. It will also determine how frost action is modified by chemical and mineral admixtures, by aggregate characteristics, and by environmental factors such as partial drying and rewetting. The data and conclusions will be used to formulate criteria and procedures to assess the freeze-thaw durability of concrete and aggregates and to develop methods and means for their improvement.
4. Non-Destructive Tests for Quality Control/Condition Analysis of Concrete

There are several areas in concrete practice related to highways where a non-destructive technique would be most desirable. A satisfactory quality assurance program which could ensure that the finished concrete is structurally sound and adequate for the intended purpose is an absolute necessity for any construction work. Present tests take too long and use specimens which may not be representative of concrete in the structure. The durability of concrete is dependent on many factors including air-void characteristics. However, simply achieving the specific volume of air in concrete does not assure adequate freeze thaw durability. More important is the size distribution and average spacing of entrained air voids. The most desirable time to determine these parameters would be prior to the placement and hardening of concrete. Presently no method can accomplish this. The moisture content of concrete has a direct effect on many durability-related phenomena such as freezing and thawing, alkali-aggregate reactions, drying shrinkage and stress corrosion. There are no reliable instruments available to determine the moisture content or relative humidity of field concrete. Present concrete technology does not have any reliable means to evaluate the internal condition of hardened concrete. A test which could measure the residual strength and conditions of concrete would enable more effective planning of repairs and rehabilitation activities to extend the service life of concrete.

In recent years significant advances have been made in the development and application of non-destructive techniques in the evaluation of products made from a variety of materials including ceramics, polymers, metals and composites. Successful application and extension of these developments to concrete might just be the breakthrough needed to solve the above mentioned problems in concrete practice. Development and application of innovative non-destructive evaluation technology to concrete will be the subject of this research.

5. Expert System for Durability Diagnostics

This study will develop a computer-based expert system for use in concrete durability problems. Such an expert system would allow the user to diagnose concrete material problems, select concrete materials and mix designs for successful rehabilitation of structures and, in case of new construction, for designing for adequate performance in the environment of interest. The study will develop knowledge bases for factors affecting concrete durability such as freezing and thawing, sulfate attack, alkali-aggregate reaction, etc. using the available information and data. These knowledge bases will then be integrated into the computer program. The complete expert system will be thoroughly documented, tested, and made available to state highway agencies.

The Congress authorized SHRP funding when it passed the Surface Transportation Act of 1987 in April 1987. The pace of SHRP activities has now considerably accelerated. The program announcements (request for proposal) for the first quarter of fiscal year 1988, issued in June 1987, mark the beginning of its most important function. With this, SHRP has initiated the much-needed and long-awaited research drawing upon the best talent and technology available to solve problems that have plagued the nation's highways for decades.
DEVELOPMENT IN BRIDGE DESIGN, CONCRETE ROAD BUILDING AND CONCRETE BLOCK PAVING IN THE NETHERLANDS

Jan van der Vring
Stichting studie centrum wegenbouw
Arnhem
Netherlands

ABSTRACT

The contribution will give the headlines of new developments in design specifications for bridges built in concrete. Special items are the influence of temperature on joint behaviour, creep in wide span constructions and the bearing of bridges.

Regarding the design of concrete roads, a comparative study has been made in order to frame an adequate design method with relevant design criteria including the influence of the type of vase and subsoil conditions.

Items concerning construction practice will be the construction of joints, curve behaviour, texturing and equipment.

Considering noise reduction and reduction of splash and spray, experiments have taken place with open graded concrete toplayers. Special items will be the design of concrete decks on lightweight bases, fills with foam concrete and the grinding of concrete surfaces in order to reduce noise production.

Examples will be given of overlays and special repair methods as well as the use of recycling materials in the road construction. Quality control is evaluated in order to get a better use of the materials available, the equipment and the money and manpower involved.

Prestressed concrete is used constructing the platforms of our main airport Schiphol near Amsterdam where very poor subsoil conditions are found.

Special attention is given to the theories behind a new design method for concrete block paving and its verification in practice by various test sections. Also the latest developments in the shape of the pavers and laying techniques will be shown.
Title of paper: Development in the Netherlands in the field of concrete and structures and concrete block paving

Speakers name: Jan J.M. van der Vring
Profession: Research engineer
Affiliation: The Netherlands Centre for Research and Contract Standardization in Civil and Traffic Engineering (Centre R.O.W)

1. INTRODUCTION

Since 1970 the building of concrete roads in the Netherlands has almost stopped. The reason for this was the fact that the concrete roads that were constructed earlier had undergone the trafficboom of 1955 - 1970 very badly and most of all the very low price of the bitumen made it more attractive to build the cheaper asphaltic roads. Only the Province of Noord Brabant kept on laying concrete roads. This resulted in a great loss of experience and knowledge in design and practice by all the authorities and constructors involved. Only within the C.R.O.W. research centre a workinggroup was studying the subject and in the City of Amsterdam some testsections were laid down.

The authorities concerned are:
- the central government ("Primary" roads)
- the provinces ("secondary" and "tertiary" roads)
- the municipalities ("quarternary" roads)
- the "polder" boards.

Today, the interest in design and construction of concrete roads is growing steadily resulting in some new sections of highways and overlays. This can be explained by the high prices of bitumen and the preference for low maintenance and durable pavements. To pick up a deeper understanding of the newly developed design methods, technology and practice, a lot of research was done and is still on its way. In this contribution the most important research-projects are reported briefly. More details are available at the Centre R.O.W as a neutral coordinating institute for Research on road building and traffic questions in the Netherlands.

This contribution has been affected based on information from:

Ir. M.P.J. Vereyken CUR, Gouda
Ir. A. Penning Dienst Weg- en Waterbouwkunde Rijkswaterstaat, Delft
Ing. P.E. Vogelaar
Dr. Ir. E. Vos
Ing. D. Endeveld Directie Zuiderzeewerken Rijkswaterstaat, Lelystad
Ing. E.J. van Harten Vermeer, Hoofddorp
Ir. L. Houben Technische Hogeschool Delft
Ir. M. Leewis Vereniging Nederlandse Cementsindustrie (VNC), 's Hertogenbosch
A.A. van der Vlist
Ir. Drs. J.J. Swart Provinciale Waterstaat Noord-Brabant, 's Hertogenbosch
Ing. F. Smits Cobeton, Amsterdam
Ir. D. Stoelhorst Bruil, Arnhem
2. BRIDGES AND VIADUCTS

Chloride-penetration in bridgedecks

In the Netherlands we have a temperate maritime climate with an average January temperature of 1.7°C and a July average of 17°C. The total annual precipitation of nearly 800 mm is evenly distributed throughout the year. To prevent our roads becoming slippery by snowfall or ice, the procedure today is to use automatic salt spreaders. Although temperatures in winter do not tend to drop to extremely low levels, the many changes around the freezing point and the rather humid conditions do cause a lot of salt spreading. Therefore within the research Centre R.O.W, the danger of concrete affection by de-icing salts on structures was investigated.

In 1976 18 bridges and viaducts built in concrete and divided in three categories: 0 - 4 years old, 4 - 10 years old, older then 10 years, were inspected by a special working group.

The inquiries were focussed at the following aspects:
1) quality of the concrete right under the asphaltic top layer
2) presence of de-icing salts (chlorides) in this concrete
3) the density of the asphaltic toplayers
4) the affixture of the asphalt to the concrete.

Per structure 5 - 15 cores were taken and a visual inspection was carried out.

The findings of these investigations were that there is no need for a special protection layer between the concrete and the asphalt because in most of the cases the concrete under the asphaltic layer was in a good condition.

In our neighbouring countries however a protection layer is practice. Just to be sure this investigation was repeated in 1986 on twelve of the structures inspected in 1976.

Per structure 2 - 9 cores were taken on almost the same places as was done in 1976 and again a visual inspection was carried out.

The conclusion of this research was that the increase of the average chloride content was not worth mentioning and there still was no need for using a protection screen between the concrete and the asphalt against de-icingsalts. The reason for this is the good quality of the concrete used (B 37,5) water/cement ratio 0.40 - 0.45, cement content 346 - 360 kg/m3, and most of all the quality control during construction based upon strict regulations. These regulations are in agreement with the standards developed in the European Committee for Standardization (C.E.N.)

A specific manual for designing calculating and executing concrete bridges incorporating all these standards will be published in 1988 and the draft is now laid down for comment.

3. CONCRETE ROADS

3.1 Design factors

Unreinforced concrete pavements on subsoils, sensitive to settlements

In a large part of the Netherlands compressible soil conditions can be found. Construction of roads in these areas means that differential settlements are to be faced. In 1983 the Road and Hydraulic Engineering Division of the Department of Public Works initiated research into the behaviour of unreinforced concrete roads, subject to differential settlement of the subbase. This research comprises the following aspects:
- What are the determining characteristics of differential settlement influencing the structural behaviour?
- What is the effect of differential settlement on the minimum thickness of the concrete slab?

A calculation method was developed by using a model based on soil mechanics and material characteristics and this calculation method was also verified in practice on a road, built in 1964 with rather serious settlements although very few cracks had occurred. The slabs, placed directly on the sand subbase, were dowelled (length 6.25 m, thickness 0.23 m).

If a sine-shaped approximation to the actual pattern of settlement is assumed, the curvature parameter $\delta/T^2$ is the most important parameter (see fig. 1).

This parameter determines the magnitude of the stresses in the concrete slabs caused by the differential settlement.

To estimate $\delta/T^2$ needed for the design, relative to soil mechanics, that in case of an area where differential settlement can be expected, the alignment must be characterised by detailed settlement profiles based on the geological model in combination with the local infrastructure (crossing ditches, dikes, engineering structures etc). The calculation study for the design of a motorway shows a permissible value of $\delta/T^2: 25 \times 10^{-5} \text{ m}^{-1}$.

This means that for a half wavelength of $T = 10 \text{ m}$ a settlement amplitude of only 0.025 m is permissible, but for $T = 40 \text{ m}$ the settlement can be 0.40 m. If it is expected that only a few slabs will lie at a critical place, the chance is small that the actual tensile strength of those slabs will be less than the characteristic value (lower limit) for the tensile strength used in the dimensioning calculation. In that case an extra concrete thickness is not necessary.

If differential settlement is expected as a result of $\delta/T >> 25 \times 10^{-5} \text{ m}^{-1}$, there is a very solid chance that the concrete slabs will always crack prematurely. In such a case geotechnical measures have to be taken in order to keep the settlements within limits after the concrete slabs have been placed.

### 3.2 MATERIALS

#### 3.2.1 Foam concrete

Already in 1920 foam concrete has been used with success on a small scale. New developments and techniques have made this material very suitable for special applications yielding very satisfying results in a technical and economical way. Because of the low mass density (400-1800 kg/m3) compared to other foundation materials, the use of foam concrete is particularly attractive in areas with poor bearing capacity of the subsoil and consequently severe settlements.

Foam concrete is obtained by mixing foam into a mortar consisting of cement, sand particles (< 4mm) and water.

It is manufactured in place by mixing the mortar, usually obtained from a plant with the foam produced on site by a foam generator.

The discontinuous mixing is done in the truckmixer. The foam concrete mortar
is very fluid and can be pumped to the processing place up to a distance of 250 m. The high air content makes a suction pump unsuitable so that a rotor pump or displacement pump is needed. No compaction is needed and the leveling can be done easily by pulling a beam over the surface. Curing must be applied to prevent the surface from drying out.

The mass density can be varied by changing the content of the cement and sand compared with the amount of foam. This is depending on the purpose for which the foam concrete is used like isolation against temperature differences, lightweight constructions, drainage of water, resistance against water penetration.

The mechanical properties like strength, elasticity and water suction are improving rapidly if the mass density increases. Figure 2 and 3.

Many test sections have been realised during the last 7 years and the experience obtained in design, material properties and execution have resulted in a more or less routine today. An example of a construction is given in figure 4.

### 3.2.2 Portland fly ash cement

In the Netherlands blended cement like blast furnace cement is used over 50 years. It is a blend of 40% portland cement clinker with 60% blast furnace slag and a little bit of gypsum. Since 1982 a new type of blended cement has been manufactured. It is based on Portland cement clinker with 10 - 30% powdered fly ash from coal burning power stations.

The manufacturing process produces a cement whose properties are comparable with those of ordinary class A Portland cement. Meanwhile a standard for the new type of cement has been laid down in NEN 3500 under the name of "Portland
fly ash cement

This kind of cement is prescribed for top layers of Dutch concrete roads to prevent surface damage as a result of the combined action of frost and de-icing salts (scaling). In practice Portland fly ash cement appeared to be very easy to use compared to Portland cement, obtaining even higher compressive strengths.

The resistance to frost and de-icing salts was not known. Therefore a comparative investigation was carried out by constructing five test sections laid out in a cycle path 2.50 m wide with a toplayer thickness of 0.16 m using a slipform paver. Preinvestigations by the contractor showed that to obtain the 4% air content, necessary for good frost resistance, more air entraining agent had to be added in the case of Portland fly ash cement than in the case of ordinary Portland cement. Both the normal quantity and double the quantity of air entraining agent were added, see table 1. During laying, it was apparent that the mixtures containing Portland fly ash cement were easier to handle than the comparable mixtures using Portland cement. This coheres with the plastifying effect of the fly ash particles. The spherical shape is thought to cause this effect. The roadsurface was textured with a fine broom and protected by a curing compound on a resin basis. About three weeks after laying, four cores were taken from each section, one core to determine the wear resistance (sand blasting test) and the other cores to determine the compressive strength after 28 days (bottom part of each core) and the resistance to frost and de-icing salts. The top of each core was covered with a layer of water (± 3mm). Then the cores were subjected to 40 freezing thawing cycles (duration of one cycle: 24 hours) the temperature dropping to -5°C.

After each cycle, salt was sprinkled on the frozen water on top of the cores and pieces of concrete loosened as a result of the temperature shock caused by de-icing of the water layer. The loosened particles were sampled and it was possible to put the results of these tests in a table.

The findings were that concrete made by using Portland fly ash cement was stronger than the corresponding concrete with Portland cement. Resistance to wear and scaling was better for the Portland fly ash cement than for the Portland cement. Portland fly ash cement is now being used extensively in Dutch concrete road construction.

Works recently carried out are National Road A1 and National Road 73. Portland fly ash cement was used both in the lean concrete base layer and in the toplayer.

Table 1: Data concerning the five test sections

<table>
<thead>
<tr>
<th>cement</th>
<th>air entraining agent (ml/m3)</th>
<th>air %</th>
<th>compressive strength after 28 days (MN/m²)</th>
<th>weight loss during sandblasting (g)</th>
<th>weight loss after 40 freezing cycles (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Portland A</td>
<td>250 (normal)</td>
<td>4.0</td>
<td>45.8</td>
<td>21.5</td>
<td>0.3</td>
</tr>
<tr>
<td>2 ,,</td>
<td>-</td>
<td>1.6</td>
<td>55.5</td>
<td>19.3</td>
<td>6.5</td>
</tr>
<tr>
<td>3 Portland fly ash A</td>
<td>250</td>
<td>2.1</td>
<td>51.1</td>
<td>17.9</td>
<td>0.3</td>
</tr>
<tr>
<td>4 ,,</td>
<td>500</td>
<td>4.0</td>
<td>48.9</td>
<td>22.9</td>
<td>0.3</td>
</tr>
<tr>
<td>5 ,,</td>
<td>-</td>
<td>1.7</td>
<td>59.9</td>
<td>19.0</td>
<td>3.1</td>
</tr>
</tbody>
</table>
3.2.3 Recycling of concrete and brick rubble

Today in the Netherlands building materials like aggregates are growing scarce. On one hand this is caused by the increase of demand, on the other hand diggings places are getting worked out while potential new sources very often are protected by environmental laws. Also an increase of the amount of rubble to be shot can be established. In the Netherlands a lot of breaker plants are in action to make this rubble suitable for re-using.

Using these materials is a partly solution of the waste material problem. Various experiments have shown that broken concrete and brick rubble mixed with sand can be used very successfully in cement concrete for roads. Breaker plants are able to deliver every mix that is asked for, even 100% concrete rubble. Before allowing the use of broken rubble in cement concrete for roads, it must be established if this material will meet the requirements on resistance to frost action and de-icing salts and if it can be handled by the existing paving machines (for instance a slip form).

In a cycle path two test sections of approximately 15 m length were laid using concrete rubble and brick rubble respectively as a coarse aggregate in the concrete. The < 3 mm fraction was sieved away.

In advance the rubble was wetted to prevent water being drawn from the mortar by the porous aggregate, inhibiting the cementation of the granules.

The following concrete mixture were made up at a concrete plant:

**Cement concrete with concrete rubble**
- 65% concrete rubble 3 - 30 mm
- 35% coarse sand
- 365 kg/m³ Portland cement
- w/c factor 0.47

**Cement concrete with brick rubble**
- 60% brick rubble 3 - 30 mm
- 40% coarse sand
- 365 kg/m³ Portland cement
- w/c factor 0.56

The rest of the cycle path was made in cement concrete with gravel as an aggregate and regarded as a reference for the two test sections.

An air entraining agent was added for all the three mixes.

Manufacturing the special mixtures created no problems and also the handling with the slipform paver proceeded without any difficulties. The compressive strength and the density of the bottom part of the cores were determined at an age of 28 days. The top part of the cores was used for freezing/thawing test.

The results are given in table 2. Concrete with brick rubble showed the lowest strength and resistance against scaling.

After the first winter pieces of the surface of the brick rubble test section had loosened. This damage was clearly observed by the red colour of the brick particles. It is not clear whether the damage was caused by expanding components in the rubble or by frost/de-icing salt action.

Very slight functional damage was determined and no further deterioration has occurred after that. The use of brick rubble as an aggregate for cement concrete pavements therefore is subjected to several restrictions and it can be considered in certain circumstances. A repetition of this practical experiment is intended in order to check if the damage experienced will occur with any type of brick rubble and to investigate the real causes.

Meanwhile recommendations have been drawn up for requirements and tests relating to the approval of concrete rubble and brick rubble as coarse...
aggregates for concrete. These recommendations can be regarded as preparatory to a Dutch standard.

Table 2: Density, compressive strength after 28 days and weight loss after 40 freezing/thawing cycles

<table>
<thead>
<tr>
<th>coarse aggregate</th>
<th>density (kg/m³)</th>
<th>compressive strength after 28 days (MN/m²)</th>
<th>weight loss after 40 cycles (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gravel (normal)</td>
<td>2355</td>
<td>51.3</td>
<td>0.13</td>
</tr>
<tr>
<td>concrete rubble</td>
<td>2275</td>
<td>48.3</td>
<td>0.11</td>
</tr>
<tr>
<td>brick rubble</td>
<td>2165</td>
<td>36.3</td>
<td>0.99</td>
</tr>
</tbody>
</table>

3.3 CONSTRUCTION PRACTICE

3.3.1 Direct asphalting of a fresh sand-cement stabilisation

Since 1956 stabilising sand with cement as a subbase has become a more common practice in the Netherlands. This kind of stabilisation is used as an operation platform to carry out the rest of the road construction activities. Initially, dimensioning these layers was based on experience. Devised by the Association of Stabilisation Contractors and in collaboration with the Netherlands Cement Industry Association a more scientific method has been published. This publication distinguishes four types of construction:

a) asfalt - sandcement - subsoil
b) concrete blocks - sand cement - subsoil
c) wearing course - sand cement - subsoil
d) concrete - sand cement - subsoil

In practice the construction of a stabilisation means the mixing of sand, cement and water in place or in plant, the compaction of the layer and the covering of the layersurface with bitumen emulsion to prevent drying out and to become a good adhesion to the concrete or asphalt layers on top of it. In the case of an asphalt construction the rest of the asphaltic construction can be applied after some days. Contrary to this conventional method of laying, a test was carried out by applying the bitumen emulsion and the first layer of asphalt within 24 hours after a certain degree of hardening in the stabilisation layer has been achieved.

This research was carried out on a number of test sections by the Netherlands Department of Public Works in cooperation with the Association of Stabilisation Contractors.

The following results have been found:

- Research into the crack formation behaviour of the stabilisation layer shows that in the case of direct asphalting less shrink cracking and, consequently, less reflected cracking occurs in the asphalt layer, whilst the crack-width is smaller than with the conventional method.
- Falling weight deflection measurements on two three-year-old road sections indicate that the rigidity of the directly asphalted section is greater than that of the conventionally laid section.
- Shear tests on drilled cores Ø 150 mm indicate that a good bond can be
achieved by using 0.5 kg/m² cationic bitumen emulsion type 0 sprinkled with 3 kg/m² and 2/6 chippings.

Since in the case of direct asphalt ing the 'fresh' stabilisation layer will be driven over by construction traffic within 24 hours, this aspect has also been investigated, with the following results:

- if stabilisation is carried out at low temperatures (< 5°C) the construction traffic will give rise to rut formation;
- at higher temperatures (> 10°C) there is no significant decline in the strength of the stabilisation layer as a result of construction traffic;

However, some rut formation was observed (± 10 mm at 11°C).

With efficient deployment of men and resources, the 'direct asphalt ing' method does not turn out to be more expensive than the conventional method, and savings can be made by dimensioning the asphalt pavement more accurately.

3.3.2 cracking in lean concrete base layers

Cracks forming in lean concrete base layers caused by shrinkage can be regulated by inducing joints in the fresh concrete at fixed distances or providing a more or less "wild" crack pattern by directing the construction traffic over the just hardened base layer. The last method was tested in 1985 on National Road 73 which is a 10 km long section of 0.22 m thick concrete over 0.15 m lean concrete foundation. During the discussions over this way of practising, it was feared that in some places an insufficient number of cracks would develop, resulting in crack width so large as to cause reflected cracks in the concrete toplayer. Also serious damage was feared on spots where construction traffic turns around or a great deal of traffic had to pass.

A solution was chosen by allowing the construction traffic to drive over the lean concrete as soon as possible so that the crack building up was initiated as quickly as possible. Organisational measures were taken to ensure that in the initial phase every place of the surface became under traffic. Where few transverse cracks were visible an extra load was deliberately applied to the foundation. This method appeared to be easier to carry out in practice as expected.

In particular the moment the construction traffic could be admitted on the lean concrete proved to be not very critical for the desired crack pattern. This approach afforded some insight in the quality of the lean concrete foundation.

At some places where the quality was low the top layer lost material. On these places the thickness of the concrete top layer will be a few centimetre more and compensating the reduced load bearing capacity of the foundation.

The result of these test was that allowing construction traffic to travel over the foundation offers several advantages in practice:

- a more flexible execution of the job can be obtained while it is possible to save on the costs of access and exit roads.
- No extra costs are needed for special cracking devices like a drop knife.
- Through deliberate track shifting the foundation will reach a fairly uniform crack pattern, preventing stresses that might lead to wide cracks and even to reflected cracking in the pavement.
— Places of inadequate quality are spotted at once and can be taken care of before the top layer is applied.
— The admission moment for the construction traffic on the lean concrete (after hardening for a few days) is not very critical for the required crack pattern.

3.3.3 Vacuum treatment of concrete

From literature it was taught that vacuum treatment of cement concrete can be of advantage for certain situations. When quick repair of pavement is needed and high quality surface characteristics are required, this method can be in favor against others.

Using experience from Scandinavian countries, where vacuum treatment is well known, two test sections were built to compare a conventional method with the use of vacuum treatment on wearing courses. A high wear resistance and a maximum adhesion of the wearing course to the structure had to be achieved.

Although the scale of this test program was limited, combination of the results with the experiences gained from other comparable projects gives way to the following provisional conclusions:

— the resistance to wear of vacuum concrete is greater than that of conventionally processed concrete;
— the bonding strength of vacuum concrete is certainly not less than that of conventionally processed concrete. Indeed, the first results give reason to think that the bonding strength of vacuum concrete will prove to be greater than that of conventionally processed concrete;
— the sensitivity to weather of vacuum processed concrete shows a marked decline compared to conventionally processed concrete;
— the additional costs of vacuum processing are offset by the lower costs of pre-processing the construction concrete and lower costs of the concrete mortar itself.

3.4 MAINTENANCE AND MANAGEMENT OF ROAD SYSTEMS

3.4.1 Visual inspection of concrete roads

The realization of the present modern net of motorways in the Netherlands was started about 30 years ago and by now it is almost finished. This net must be maintained and reconstructions or even renewals are necessary because of unexpected increases in traffic or due to the fact that the first motorways that were finished soon will reach the end of their design life.

The financial sources for this are limited and methods are to be found to carry out these activities according priorities that are based on technical and rational arguments. Therefore within the Centre R.O.W a system was developed to gather data about the road system under management, to store them, to establish priorities for maintenance, repair and rehabilitation and which measures have to be taken. Based upon this system the Province of Noord Brabant has developed a system of visual inspection for its concrete roads which has been employed successfully for a number of years. The system enables the district officials to carry out rapid and unambiguous inspections of concrete pavements. These inspections are directed from a central office where uniform instructions are given in order to create the best consistency of judgment. The system distinguishes between an overall and a detailed visual inspection. The latter is only carried out for those pavements which are assessed to be in a bad or very bad state by reference to one or more
damage categories. The visual inspection provides information on the seriousness, extent and location of each damage pattern encountered. This information is the basis on which the programme for incidental, minor or major maintenance is founded. Beside these damage patterns, future function of the road, traffic volume and road safety play a part in determining urgency priorities.

This system of visual inspection produces a lot of data which are entered on special designed computerready forms. This gives the opportunity to process the data by a computer so that a rapid indication for the measures to be taken can be obtained. This priority sequence system has a national basis. It is meant to be an instrument by which the authority in charge will be able to make his choice based on the right arguments.

Comparison of the data for successive years will give a picture of the extent of deterioration of the concrete pavements and studying this information will give the trends to be distinguished and the conclusions to be drawn from it.

3.4.2 Overlays on flexible pavements

In 1977 and 1978 four adjacent testsections were built as an overlay on an existing asphaltic motorway.

Testsection 1: 2,5 km cementconcrete pavement with longitudinal reinforcement with a thickness of 0,165 m.

Testsection 2: 1,5 km unreinforced cementconcrete pavement with a thickness of 0,21 m.

Testsection 3: 2,0 km asphaltic pavement (normal design life) with a thickness of 0,08 m minimum.

Testsection 4: 2,2 km asphaltic pavement (long design life) with thickness of 0,15 m minimum.

The existing pavement consisted of asphalt on a lean concrete base and on good subsoil conditions.

There were three significant reasons for laying these testsections:

- gathering recent experience by the Department of Public Works in the application of cement concrete pavements. (All the new works were carried out in asphalt by that time).

- Comparison of the costs of laying and the operating costs of cementconcrete and asphaltic constructions.

- Studying the behaviour of the different pavements from the time of laying until the end of their service life.

The testsections have been under traffic for more than 5 years and an intermission report was published.

The most important conclusions are:

- The road-end anchorages used, consisting of four ground anchors, were unable to prevent continuous expansion, as a result of which the plastic joint transitions had to be repaired and trimmed before a new rubber profile could be fitted.

- The reinforcement percentage in the test section of continuous reinforced concrete (0.72%) was too high.

An average crack distance of 1.5 to 2 m had been anticipated. The crack distance has currently become stabilised at approximately 1 m. It is expected that the desired crack distance will be achieved with a reinforcement percentage of approximately 0.65%.

- In the test section with unreinforced concrete, over the course of time it has been possible to determine at ever greater distances from the end of the pavement that the concrete is no longer completely bonded to the asphalt. This was concluded from the increase in deflection measured at the
transverse joints. No deflection is yet being measured in the middle of the road. As a matter of fact the deflection found in the loose slabs was limited to some tens of microns, whilst after an initial increase the value has remained stable for some years.

- The texture depth for both the concrete and the asphalt decreased to a value of approx. 0.4 mm. This value has remained unchanged over the last few years.

- In one section of the road English sandstone was incorporated as a coarse aggregate in the concrete. Compared to crushed stone this aggregate shows great resistance to polishing. After five years' use, the section does not show any abnormal roughness compared to the other sections where the coarse aggregate consisted of crushed stone. After a rapid decline in the first year there has hardly been any further change in roughness.

- Light reflection from the concrete surface was better than that from the asphalt surface.

- Noise measurements showed that approx. 2-3 dB more noise was produced by traffic on the skidresistant concrete than on the asphalt test sections.

- Maintenance costs were low for all test sections during the first five years. It is expected that it will be another five years before some insight can be obtained into any differences in operating costs.

- By using special calculation techniques it is possible to get an insight in the costs of exploitation (laying down and maintenance costs together). Cement concrete overlays are in this case more expensive than asphaltic overlays. Because of the fact that the maintenance costs still have a very heavy influence on the exploitation. More relevant information will be gained after 15 or 20 years.

3.4.3 Local repair

Disturbance of todays dense traffic has to be minimalized because of the safety problems and user costs.

For the quick repair of damaged unreinforced pavements a method has been developed with a minimum of hindrance for the traffic flow.

The method contains the replacement of damaged slabs by prefabricated reinforced slabs. The dimensions of these slabs are the same as the lane width and the length of the slabs in the existing unreinforced pavement. The thickness of the reinforced slabs is 0.25 m.

The pavement foundation must be brought to the exact depth required because of these thickness and a special machine has been developed for this purpose.

The execution procedure is split up in the following stages:

1. Traffic lights are installed. The lane to be repaired is closed.
2. The place to be repaired is measured in terms of dimensions, shape and transverse crossection and the measurements of the specific repair slab are checked.
3. The guide rails for the sawing machines are assembled.
4. The existing pavement is sawed twice across the road and along the longitudinal joint. The depth of sawing is 300 mm so that the saw will penetrate the foundation by 60 to 70 mm.
5. The damaged concrete pavement and foundation are broken out, a crane, wrecking hammer and dragshovel are used to remove the loose material.
6. Lean concrete is produced and a levelling board, joint filling material and vibratorplate are brought up.
7. The lean concrete is applied.
8. The prefabricated slab is brought up.
9. The crane is set.
10. The slab is unloaded from the low loader (during this phase the road is completely closed for about 15 minutes).
11. The new concrete slab is placed.
12. The edges are finished.
13. The crane is removed and the materials are loaded.

Finally the road closure equipment is removed.

This repair method is competitive with existing ones in the repair time needed and costs. The total repair takes much less time than the time available between two rush hours of a particular day.

It is not affected by the temperature and therefore the quality of the whole operation is accordingly not affected by the weather.

The lean concrete has been opted for, while the new foundation immediately must be able to bear the acting traffic loads. This can be achieved by using a layer of coarse aggregate and cement whose composition is such that initially the loads fully can be borne by the granular skeleton. After some time, the hydraulic binding of the cement will create a foundation whose properties correspond with the adjacent foundations.

4. CONCRETE BLOCK PAVEMENTS

4.1 Design of roads built with small elements

In the Netherlands we have a very long tradition in paving streets with small elements such like bricks. Nowadays precast concrete blocks are a highly accepted paving material due to their excellent town street characteristics. They are used in built up areas such as residential and shopping streets, pedestrian areas, squares and yards, parking places, etc. They also provide an ideal surfacing for heavy duty pavements like container terminals and similar port areas.

In the early eighties, several activities were started in order to develop a design method for concrete block paving, first of all for lightly and medium traffic areas such as town streets, etc. These activities were undertaken by:
- the Working Group D3 "Design of concrete block pavements" of the Netherlands Centre for Research and Contract Standardization in Civil and Traffic Engineering (Centre R.O.W). Fallingweight and level measurements on test sections under actual traffic were carried out, along with an analysis by the finite elements method.
- The Road Department of Public Works of the City of Amsterdam. This research comprises falling weight measurements, pull out tests and soil pressure measurements along with an analysis by the finite element method.
- The Delft University of Technology in Delft. Fallingweight and rut depth measurements on actual block pavings were carried out, including the ECT Container terminal in Rotterdam.

Analysis by the finite element method was also regarded.

Among these three institutes a close collaboration existed, particularly for the use of the ICES-STRUDL Finite-element programme 'Rigid Bodies', developed by the Delft University of Technology. In this two-dimensional, plane-strain model the blocks are represented by 'rigid-body' elements joined to each other by vertical springs too. The bedding sandlayer is schematized by vertical springs and the lower layers are represented as continuous elements.

With this program an excellent correspondence between measured and calculated
deflection curves was obtained. Design charts which are believed to be applicable to typically Dutch conditions are available now. The rutting depth condition is the most predominant design criterion. The results of deflection and level measurements on 10 test pavements (i.e. the elastic and permanent deformations respectively) were analyzed and this resulted in two (provisional) design charts for concrete block pavements with an unbound subbase. This includes the sandy subbases which are most common in the pavement structures in the Netherlands. The final design charts will be published in the concluding report of the Working Group D3, to be expected early 1988.

4.2 Concrete block shape and laying equipment

The concrete blocks used in the Netherlands are usually of a rectangular shape. They are easier to produce, are less vulnerable to damage and easier to lay down. The better interlock capacity that irregular shaped blocks are supposed to perform are considered of a minor priority for the Dutch circumstances. The way the pavement is locked up between the curbes along the pavement and controlling the width of the joints between the blocks is of a higher importance. The performance of the pavement is highly determined by the quality of the laying pattern but most of all by the kind and quality of the base layer. This is based upon the very long experience we have and was confirmed in the results obtained from the test sections built by the Working Group D3.

Considering the concrete block itself a lot of developments are on their way. Experiments have been carried out by giving the rectangular blocks small ridges on the sides. This will result in a better fixed joint-width and through this a more regular laying pattern.

The material in the joints between the blocks plays a very important part in the performance of the pavement. The joints must be filled properly in order to prevent damage by scaling of the block edges and to built up the right capability for shearstrength between the blocks.

Therefore, a new blockshape has been brought into practice by narrowing the top of the block a little bit. In this way a wedge shaped joint is formed between two blocks in which the fill-material can penetrate easier.

Another development is the manufacturing of open graded concrete blocks. This enables the rainwater to drain away in the subsoil which can be of importance for special applications were planting must be kept in good condition. It is expected that this kind of block will reduce the noise production from the contact between rolling tire and pavement.

Very recent experiments are carried out by using waste materials as an aggregate in concrete blocks. Incinerator slag and fly ashes are the major materials used. The objects for this experiments are the durability, cost-effectiveness, environmental consequences, qualitycontrol and production conditions.

Laying blocks by hand is very hard labour and needs skill. Many paviors suffer back complaints and other errors in health after reaching the age of forty years. Due to this social indication and to improve productivity, mechanically laying is in progress. In the early eighties, the "Delta S" paving machine was developed in the Netherlands.

Blocklaying machines of this type were used for both large-scale projects (800.000 m² on ECT’s second container terminal in Rotterdam) and some smaller
scale projects e.g. streets in the city of Rotterdam.
Furthermore new types are being developed in the Netherlands such as using
vacuum lifting techniques. The use of paving machines increases productivity,
lowers the costs and improves the working conditions of the paviors.
DURABILITY OF ROAD AND BRIDGE STRUCTURES OF CONCRETE - NORDIC EXPERIENCES

Dr Bo G Hellers

SWEDISH CEMENT AND CONCRETE RESEARCH INSTITUTE

Abstract

The concept of durability is old and new. It has been known for as long as man has erected structures, such as road and bridges, that without maintenance they will deteriorate under the sun and eventually disappear. Even with maintenance, exercised in intervals, the structures will become sensitive and feeble. It may not be advisable to continue the maintenance beyond a certain point in time.

From such intuitive observations some coarse conclusions could be drawn - such as choice of materials or drainage performance to avoid frost action.

The new approach to durability is to treat deterioration with scientific tools. A probable mechanism of decay is expressed in mathematical form, based on experimental observation.

An established mechanism contains the possibility of variation, to highlight various effects from materials composition, environmental exposure and form.

In the Nordic countries experiences with failing durability have been collected over the last 15 years. Well interpreted they give ample advice on design and detailing of structures.

Besides, research has found new materials compositions for long life performance.
Looking ahead, traffic structures may be required to perform even better, carrying increased loads with less accident occurrence and less noise.

The maintenance question is treated in economical terms to find good combinations of performance and limited maintenance costs.
1. INTRODUCTION

It has fallen upon me to summarize Nordic experiences of a structural material, concrete, when used for traffic structures such as roads and bridges.

First, it must be understood that a responsible position in Sweden does not give automatic qualification to talk for others. Therefore, I must start by saying that the experiences from other countries than Sweden are interpreted by me from investigations performed by others, not by me or my institute.

Also, it must be brought to attention that the conditions of our countries for concrete structures, in construction and maintenance, are fairly different.

All countries have different brands of cement being produced domestically and dominating each market.

The conditions of sand and gravel are likewise varying over the map. Good natural conditions in most of Finland and Sweden are not quite so good in Norway where other petrographic strata are predominant. In Denmark conditions get even more sensitive since there is risk of expansive reaction phenomenon taking place between the binder and some reactive gravel.
In the Nordic countries concrete is the outstanding structural material for bridges while concrete has only a trifle part of the road structures.

In short, I believe that there is good reason to say that concrete should remain the outstanding material for bridges, possibly in combination with other structural materials such as steel for part of the superstructure.

But there is every reason to believe that in the future, road structures will engage much more concrete for strength, durability and economy, again possibly in combination with other materials such as geotextiles and asphaltic concrete for surface properties.

2. CONCRETE FOR ROAD STRUCTURES

Heavy traffic requires hard surfaces for speedy and safe deliveries. For such a surface several requirements must be obtained — above all it must have such smoothness to carry the traffic comfortably without too much wear, it must have such roughness under all circumstances to ensure friction for braking and it must perform endurably.

Such performance is possible to obtain by binding the layers in the road structure, not only the surface layer but also the base layer. Most often bituminous products have been used as binders. Good performing binders as they are, they supply the road structure with eminent tensile capacity. A superimposed deformation of the road from frost action or subgrade sliding will most often not destroy the structure since the asphalt keeps it intact.

But this sort of precautionous thinking is related to a limited level of road engineering, not likely to be developed, also for cost reasons.
Another binder of different character is cement, or rather cementitious materials.

They will provide a road structure with

- high compressive strength
- high modulus of elasticity
- small plastic deformations after loading
- low cracking strain
- temperature independent material properties
- resistance to oil spill

The price for all this is a structure which is sensitive to superimposed deformation. Thus, it requires a high level of engineering related to subgrade conditions in order to ensure stability and prevent frost action.

It is small wonder, therefore, that a new class of superstructures in which the best properties of both alternatives are combined, is being discussed.

Referring to present state of experience it is now true to differentiate between three alternatives,

- the all bituminous structure
- the composite structures (cement bound base, asphalt bound surface)
- the all concrete structure
The volume of experience is not large. The third group touches upon the US traditional road structures, the middle group is to be considered a promising solution in which additional qualities can be included such as wheel noise damping.

2.1 Cement stabilized gravel

Many open roads were previously stabilized or strengthened on site by mixing cement into the gravel. The machinery for this procedure was well developed but the results were uncertain depending on varying gravel composition (particle size distribution).

Such roads in Sweden proved very sensitive to the use of deicing salts. In fact they were most often destroyed by frost action within one or two years.

Norwegian experiences with this road type were better.

By mixing the cement and gravel in a factory and then place it from trucks onto the road gives a much better quality control. The gravel can then be specified to standard and the mixing well done.

Also, by covering the base with a surface of asphalt concrete, the composite interaction can be very satisfactory. Several such roads have been built in Sweden and they perform well. Only very limited reflection cracking has been registered.

This structural solution is especially useful to replace a bituminous base layer when track formation is a problem. Such cases are turning lanes as well as parking pockets for buses.

With the traffic growing and the axis loads increasing it may well be wise to use this structural solution throughout.
Recent tests in Sweden for a whole road show promising results - in performance and economy.

2.2 Cement grouted macadam base layer

Another possibility attracting wide attention is the use of a well packed single-fraction macadam bed in which cement is grouted. By use of modern techniques for plasticising the slurry the water content can be held fairly low and still give the slurry a sufficient penetrating viscosity. This has been shown in Swedish experiments as well as in Denmark.

The additional use of fly-ash seems to limit the cracking, also over a longer time.

Like with cement stabilized gravel the top surface bituminous layer must be impermeable to stop salty water from soaking the binding paste. This would otherwise inevitably lead to frost damage.

2.3 Roller compacted concrete base

A new possibility to form a very strong base structure is to use heavy vibrating machinery to compact a very dry concrete. The water/cement ratio is down to 0.3 while the cement content is more than 300 kg/m³. It is a frost proof concrete even with salt so the bituminous surface topping can well be left open, that is water penetrating.

This could prevent water sliding and reduce noise level from the road, especially in the winter time when the studs run on a dry surface.
2.4 The all concrete structure

All concrete roads have been tried as far back as in the 20s, with very good results. These roads were built in Denmark and Sweden with very labour intensive methods, hand puddling and such.

Of course this was costly and since the cement was needed elsewhere the method was dropped till after the second world war. In the decades after that the Danes have built a certain proportion of concrete roads, mainly four lane highways like in Southern Sweden where this has also been tried. Experiences are good but not overwhelming. Observations have gone into the provisional code for the Nordic countries, used time and again.

The reason for a missing break-through is apparently the complex and very expensive build-up. The base layer is a 15 cm cement stabilized gravel and the surface layer is a 20 cm dense concrete layer.

The surface is roughened with steel brushes to provide friction. Joints are also provided.

The wear from studs can be counteracted by use of very high strength concrete as shown by the Norwegians.

This is a very good road structure but the noise from the rolling wheel is in no way damped.

3 CONCRETE BRIDGES

In all Nordic countries concrete accounts for more than 90% of the total. There is a recent trend towards combination of materials allowing steel to be used in the superstructure.
Concrete is a well-damping material which keeps the noise from traffic down.

The environmental load which put the bridges to an unanticipated test was the use of deicing salts, especially NaCl. It started around 1960 for safety reasons. Not until 1965 was it known for sure to be very hazardous to the durability of concrete, causing reinforcement corrosion leading to the concrete spalling off and difficult repair situations.

Almost all bridges in our four countries have now been investigated to establish their state of condition.

It is true to say that bridges built before 1965 had too high water/cement ratio and too little air content to sustain frost and salt damage.

This has later been corrected in codes requiring a limited water/cement ratio of 0.45 and an air content of 6-8%.

All bridges are insulated at the surface and the insulation is checked regularly. All rebars are unprotected but the possibility of cathodic protection is tried.

Edge beams are susceptible to frost damage from splashing water from the road. It is now tried to protect them partly with surface treatment, a coming way to prolong service life and durability of exposed concrete structures.
NORWEGIAN PRACTICE FOR CONCRETE BRIDGE DECK PROTECTION

BY Erling K. Hansen and John E. Haga*

In the mid-sixties alarming reports began coming of extensive damage to concrete bridge surfaces, especially in the U.S. but also in Norway. Reports of severe pavement wear, rutting, cracking, disintegration, and corrosion of reinforcement bar were received. These disturbing reports accelerated the development of formal standards for protection from water damage and for surfaced of bridges in Norway. The first edition of these standards was completed in 1976. In 1983 a preliminary revised edition was published. With some minor corrections and additions, these revised standards were made permanent in 1906.

The protective measures incorporated in these standards are directly linked to the causes of damage and have two main aims:

1. Water and salt are to be kept away from the concrete surface.

2. Pavement wear is not to be allowed when the concrete surface layer is thin.

Six different classes of pavement are defined, according to traffic level and amount of salt normally spread on a particular site. Criteria for choosing of a particular class are given in the standards. Alternative construction types are given for some classes. For small amounts of traffic and with little use of salt, the protective requirements are modest.

The main principle behind the protective measures is that there be complete adhesive contact between the waterproof membrane and the surface of the bridge deck. The experiences so far are good, but correct choice of materials and good workmanship are essential for satisfactory results.

* Senior Engineers at the Norwegian Road Research Laboratory, Oslo
1. INTRODUCTION

The maintenance of bridge decks has become a difficult task due to the combination of heavy traffic and widespread use of salt on roadways in the winter months. The problem of maintenance is especially acute in Norway because of the extensive use of studded tires during the long winter season we have here. Highway surfaces must therefore be constructed to withstand the damage wrought by studded tires, salt and de-icing chemicals, and from freezing and subsequent thawing of the pavement. In addition, uncomplicated methods are required for pavement repair and improvement.

Damage to bridge decks of concrete due to traffic and climatical factors first appeared in the 1960's. In the course of the 60's and 70's, guidelines for the protection of bridge deck surfaces from damage due to moisture were drawn up in Norway. Primarily, concrete bridges were thus to be given a protective surface consisting of a waterproof membrane and an asphalt wearing course where the use of salt and the amount of traffic exceeded certain limits. The principles embodied in the guidelines were little heeded, and as a result unnecessarily expensive bridge constructions appeared where there was actually no need for extraordinarily protective measures.

About 1980 the Norwegian Road Research Laboratory (NRRL) completed a study of a number of bridges in Norway and concluded that there was little need for extensive repairs and that the state of bridge surfaces generally was good compared to that found in many other countries. A number of asphalt wearing courses laid directly on the concrete bridge structures were in good shape, as well as were concrete pavements which were constructed on some of the large cantilever bridges of northern and western Norway.

As a result of this study new guidelines were drawn up and published in 1983. Criteria for determination of paving methods, with respect to traffic and salt use, were now made more applicable to prevalent conditions. Greater differentiation was allowed with respect to the need for an insulating layer (membrane) when a bituminous pavement was laid, and it became possible to pave with concrete on a wider scale than before.

In 1985 the Road Research Laboratory issued a revised edition of the guidelines. The essential change in the new edition regarded the use of prefabricated membranes.
Fig. 1. Wear on bridge deck due to traffic with studded tires. (Wearing through the waterproof membrane can bring about large repair expenditures).

2. THE 1985 GUIDELINES

Pavements divided into categories

The guidelines divide pavement categories into two groups: pavements of concrete and of asphalt. Within each of these groups the pavements are classified as follows:

A1 Monolithic structure consisting of the structural concrete poured at the same time as the concrete wearing course (wearing course = 30 mm).

A2 Monolithic structure consisting of the structural concrete poured at the same time as the concrete wearing course (wearing course >30 mm).

A3 Concrete wearing course with adhesion to the structural concrete (the wearing course poured separately).

B1 Bituminous wearing course directly on the concrete bridge deck.

B2 Bituminous wearing course with priming of the concrete bridge deck.

B3 Bituminous wearing course with waterproofing of the bridge deck.
Pavement categories A1, A2, A3 and B3 all provide fully adequate protection of the concrete deck, as long as the Portland cement concrete overlay is greater than 60 mm.

Pavement categories A1, A2 and A3, when the Portland cement concrete overlay <60 mm, and categories B1 and B2 do not give 100% protection of the bridge deck. The risk of deterioration and damage to the concrete has to be compensated for by an intensified inspection of the bridges.

Pavement categories are chosen on the basis of traffic volume and the amount of salt normally used.

The need for special paving methods must be weighed carefully before surfacing a bridge. The average annual daily traffic, the use of salt, and the wear of the bridge deck are the most important factors to be weighed.

Figure 2 illustrates guidelines for determination of pavement category on the basis of traffic volume and salt use.

New construction/reconstruction of bridges, and maintenance of old bridges are considered separately.

**NEW CONSTRUCTION/RECONSTRUCTION OF BRIDGES**

- ADT: Average annual daily traffic in bridge's lifespan
- * Salt used: kg/km. trafficlane. year.

**MAINTENANCE OF OLD BRIDGE DECKS**

- ADT: Average annual daily traffic in bridge's lifespan
- * Salt used: kg/km. trafficlane. year.

**EXPLANATION OF SYMBOLS:**

* Salt used: kg/km. trafficlane. year.
** ADT: Average annual daily traffic in bridge's lifespan

Fig. 2: Alternative constructions for bridge decks as function of ADT and salt use.
Choosing between the given alternatives is done with regard to factors such as:

1) Type of bridge construction
2) Condition of the bridge deck
3) Long term plans (renovation, salting)
4) Patterns in traffic
5) Maintenance plans
6) Public expenditure.

A short description of the Pavement categories:

2.1 **A1 Monolithic structure consisting of the concrete bridge deck paved with concrete.**

The monolithic structure is the least expensive and technologically best method for laying a concrete pavement where conditions are favourable to such. The required depth of structural concrete over reinforcing steel is 30 mm, wearing course is to be poured 30 mm thick, thus a total thickness of 60 mm concrete is initially laid over the new bridge deck.

The main disadvantage with this construction is that the requirement of eveness is difficult to meet, and that with thicker slabs there is greater danger of crack formation.

Maintenance of this type of bridge also presents problems in areas with heavy traffic loads because of the low permissable extra pavement weight on the construction.

This type of bridge surfacing should thus be used with small traffic loads (mean ADT over the bridge's lifespan <2000) and when salt is not used in the winter maintenance procedures.

2.2 **A2 Monolithic structure consisting of the structural concrete bonded with concrete wearing course. (Wearing course >30 mm.)**

The development of larger cold millers in the late 70's have made this construction method more attractive. The pavement is constructed with a wearing course 60-100 mm or to a total thickness of 90-130 mm of newly poured concrete. The pavement can be milled up to 3 times for removal of ruts before the pavement requires renewal.

Monolithic poured concrete wearing course of this thickness requires a precise calculation and following up of the extent of cracking in the concrete deck. This construction method is to be chosen, and milling to be carried out, only after approval from the Directorate of Public Roads.

As regards drainage, adjoining roadways, joints, etc., one must keep in mind that milling reduces the height of the pavement, and thereby presents maintenance problems. This pavement type may be used on highways with large traffic volume and where salt is used for de-icing purposes.
2.3 A3 Concrete wearing course with adhesion to structural concrete

This method is primarily used on bridges where the superstructure is divided up into several casting sections and where there is a large risk that the surface of the structural concrete can be uneven. (Cantilever bridges, other bridges with box cross section, multi-span beam-and plate bridges).

The wearing course is usually constructed at least 50 mm thick. When the structural concrete is uneven, paving with concrete is advantageous over asphalt since the surface evenness is unaffected by post-compaction of the layer. The disadvantages of this method is the possibility for slip between the structural concrete and the pavement, and subsequent damage to the wearing course. Problems of maintenance also arise with this method.

2.4 B1 Bituminous pavement laid directly on top of the bridge deck

A bituminous pavement laid directly on top of the bridge deck can only provide protection of the deck from traffic wear, but will not provide protection of the concrete due to water and salt penetrating through the pavement. This type of bridge deck protection is thus to be used only in areas where salt is seldom spread as a part of wintertime maintenance. The bituminous pavement is laid without a special preparation of the concrete deck. However, special damage (for example protruding reinforcing bars, failures in the concrete, etc.) is assumed to be remedied before paving.

This method requires intensified inspection of the bridge deck because of the increased risk of damage to the concrete.

Such an inspection must be carried out with each subsequent repairing.

2.5 B2 Bituminous pavement with priming of the concrete bridge deck

Here the concrete bridge deck is primed with a very fluid epoxy or bituminous material to seal the uppermost layer of concrete before paving with asphalt. Priming gives a measure of protection against water and salt penetration into the concrete, but the measure of protection is not considered permanent. Ruts in the pavement can be filled over once. At the end of the first repaving period, the concrete deck needs to be inspected.

This solution requires that the concrete deck be specially prepared before the pavement is put on (removal of flaking concrete, reparation of possible damages etc.).

Warm, good weather is required and the temperature of the concrete deck must be at least 50°F (10°C) during the course of sealing. Traffic must not be allowed on the treated area (except for necessary construction traffic) before the asphalt pavement is completed.
This category of pavement can be used on bridges where salt is used in light amounts (300-1000 kg/km. lane. year).

2.6 B3 Bituminous pavement with waterproofing of the bridge deck

This construction method gives complete and permanent protection of the bridge deck (provided that maintenance is carried out in accordance with the guidelines).

The waterproofing systems in this category must be protected against structural damage and wearing away of the pavement must be avoided. Wearing away of both the pavement and water barrier will result in expensive and extensive repair work.

These systems require that the bridges are constructed for necessary additional pavement load (200 kg/m²).

In this category we now have two classified sub-categories:

B3-1 Water proofing with epoxy and mastic asphalt
B3-2 Water proofing with prefabricated membrane.

Both systems require the concrete to be thoroughly cured after pouring (minimum 28 days) before the surfaces can be paved over. Likewise, both require a prior preparation and repairation of possible scars on the surface to be paved. Both methods also require that the concrete deck is dry. Deck and air temperature is less critical when prefabricated membrane is laid as opposed to application of epoxy.

2.6.1 B3-1 Waterproofing with epoxy and mastic asphalt

The B3-1 method requires that two layers of epoxy be laid (preferably wet on wet). Sand is spread on the last layer to assure adhesion of the next layer in the construction. The epoxyfilm makes complete adhesive contact to the underlying concrete surface and at the same time creates a seal between the concrete and the layer of mastic asphalt. Thus blisters are prevented from forming in the mastic asphalt.

The mastic asphalt, which form the membrane, is laid 15 mm thick. A wearing surface of asphaltic concrete is laid on top of the insulating layer.

Good waterproofing of the concrete deck is dependent on good sealing at the shoulders of the pavement. With the help of wooden laths along the shoulders while paving, an open joint can be formed. After the pavement has been rolled and cooled down, the laths can be removed and the joint be filled with sealing compound. (A bitumen-rubber compound heated up to 356-374°F (180-190°C) is usually employed).
2.6.2  **B3-2 Waterproofing with prefabricated membrane**

In the B3-2 system the waterproof membrane consists of a preformed membrane of one or two layers (dependent on the type) which adheres to the underlying layer with the help of an adhesive asphalt. Self-adhesive types comprise another group.

In general the following conditions apply when paving:

- Prepared, clean and dry concrete-surface.
- Application of primer (ensures adhesion).
- Outlay of membrane in accordance with type.
- Overlapping of adjoining membranes to be 100 mm and 150 mm overhang on each side.
- The attachment to the gutter edges and towards groves, sinks etc., is carried out in accordance with the instructions of the producer. Should be attached carefully to prevent moisture penetration.
- Through a two-layer construction the layers are displaced so that the respective overlaps fall at least 200 mm apart.
- The protective surface of sand-asphalt or asphaltic concrete Ab4t, is laid out by hand or with a paver to a thickness of 15-20 mm after curing. It is important that the asphalt temperature does not exceed 275°F (140°C). Laying the pavement as well as the successive rolling of the surface must be carried out with caution so that the membrane is not displaced.

For the wearing course asphaltic concrete is utilized. The pavement of the B3-method is maintained by rutfilling and as mentioned above: it is important that this is done before to much wearing has occurred.

![Waterproofing of concrete bridge decks through the laying of prefabricated membrane.](image-url)
3. EXPERIENCE

3.1 Concrete wearing course

The use of concrete pavements have increased, and, in general, we have had good experiences with them. The wear has shown variations according to the composition of the concrete and the quality of the utilized aggregate.

Provided a minimum use of salt, the average wear has been 2-4 mm wear a year for ADT = 10000. The use of salt greatly increase the wear, and durability is essentially reduced.

There are two problems connected with the concrete wearing course:

- Insufficient eveness
- Cracks and lack of adhesion.

As for the insufficient eveness in the finished surface, this might be caused by the variations in the concrete forms and plastic deformation in the concrete substructure. However, poor workmanship and lack of adequate equipment have to take the main blame.

On certain bridges, the extent of areas with lack of adhesion between the wearing course and the structural bridge deck has been close to 0 % at best, however, more than 11 % of the total bridge area at worst. Cracks in the decks are almost always present, and sometimes numerous. However, investigations carried out to examine the risk of damage caused by cracks, do not give rise for alarm, with the exception of a few cases. It is common practice that the deepest cracks and large areas with lack of adhesion are sealed with epoxy.

3.2 Asphalt wearing-course

Pavement class B1 is almost problem-free. Few problems have occurred during several years of usage. Some failures of adhesion and corrugation have occurred, though.

Likewise, 7 years of experience with pavement class B2 has given few problems. A few bridges have had failures of adhesion and corrugation. It is sensitive to weather and temperature when carried out. It is valuable to strengthen the uppermost layer of the concrete. When the weather conditions are not favourable, the time aspect is a negative factor.

The solution 33-1 is, when laid out, very sensitive to weather and temperature. The formation of blisters is a large problem. After 18 years of experience it is possible to say that a good result is dependent on 100 % adhesion of all layers in the pavement. Also important is the sealing of edges near gutters, sewers and vertical planes. This is the most common permanent protection method in Norway.
Solution B3-2, the use of prefabricated membranes, also provides a permanent protection of the concrete bridge deck. It is also more independent of weather and temperature than B3-1. However, the requirements of treating the concrete base is the same for both methods. There have been some problems with lack of adhesion to the base.

3.3 Other Pavement systems

In addition to the systems chosen and described in our guidelines there are, of course, other methods for bridge deck protection.

Carried out correctly they give adequate protection of the concrete deck. Most relevant for our conditions are:

* Mastic asphalt insulation with ventilation layer.
* Water proofing with other artificial material than epoxy.
* A combination of vapor barrier membrane and wearing course of epoxy-concrete.

Such solutions are followed up with a certain degree of experimentation and sharing of experiences, and will be written into the guidelines if found to be advantageous.

4. EXAMPLES OF COSTS

It is hard to make cost comparisons due to variations in construction costs from site to site. Also the durability of pavement vary greatly from one area to another. The following costs, therefore, should be considered only as illustrative. The variations within each category can be large.

<table>
<thead>
<tr>
<th>Method</th>
<th>NKr/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>50 - 100</td>
</tr>
<tr>
<td>A2</td>
<td>≈ 50</td>
</tr>
<tr>
<td>A3</td>
<td>≈ 150</td>
</tr>
<tr>
<td>B1</td>
<td>180 - 230</td>
</tr>
<tr>
<td>B2</td>
<td>190 - 240</td>
</tr>
</tbody>
</table>

Polyuretan membrane and wearing course = kr 300-400 á/m²
Field tests with modified bitumen = kr 160-170 á/m².

5. TRENDS OF DEVELOPMENT

A combination of specific circumstances and new technology, is the reason why we again, to a greater extent, are utilizing concrete as wearing course for new bridges.
We have easy access to sand, gravel and crushed stone of excellent quality. Through careful proportioning, execution and control our concrete is generally quite durable. The use of "silica" and new additives make it possible to produce high-quality concrete inexpensively. Such concrete has shown itself to be durable against the ravages of salt and studded tires.

The additive of steel-fiber gives a more durable concrete which has good adhesion to the base.

The millers provide new possibility for maintenance and renewal. Future trends might go towards high quality concrete and thicker concrete cover over the reinforcing bars.

The thick concrete bridge deck of new constructions and gradual reduction through milling, gives maintenance problems. Through high quality concrete and thick covering (60-80 mm), an asphalt surface laid directly on the concrete will give adequate protection against vapor penetration as well as against wear. A practical solution for the future might be to utilize the concrete surface only 1 or 2 years before it is paved over with an asphalt wearing course. Then it should not be required to mill the concrete.

On the old bridges where limits of weight reduces paving options, the membrane-solution will still be required. A more extensive use of modified bitumens will also take place.

In general, we feel we have a reasonable control over the situation and do not expect drastic changes of practice in the nearest future.
THE USE OF 2 METRE SQUARE PRECAST CONCRETE RAFTS AS TEMPORARY, REUSABLE AND COST-EFFECTIVE ROADS

John W Bull
Dr and Lecturer in Structural Engineering
University of Newcastle upon Tyne
Department of Civil Engineering
Newcastle upon Tyne. NE1 7RU, UK.

ABSTRACT

In the repair and maintenance of roads subjected to high volumes of traffic, (e.g. motorways, trunk roads, etc) it is necessary to ensure the minimum traffic interruption, while frequently relying upon the utilisation of areas, such as the hard shoulder and the central reservation, which are not fully suitable for high volumes of heavy traffic.

At the University of Newcastle upon Tyne, research has been carried out into the accurate design of 2 metre square, precast concrete rafts for use in just such circumstances. These rafts are easily moveable and can be laid as a permanent or temporary road surface. The rafts are reusable and have been designed to accommodate repeated wheel loads of up to 850 kN.

The design method, takes into account the ground conditions and vehicle loadings, from which the depth of sub-base and its CBR value can be found. The units can be used to reduce soil bearing pressure and because they are factory precast, the quality control is assured. The temporary pavement life is predictable and the pavement can be laid in a matter of hours.

The paper discusses the design of units for temporary roadways, their manufacture and usage. Typical examples of the computer based design method are given.

1. INTRODUCTION - CHAPTER 1

The use of raft-type precast concrete pavement units, offers flexibility and assured pavement quality, to the highway engineer, when faced with the requirement of repairing and maintaining roads subjected to high volumes of traffic. If a section of road has to be closed off, the highway engineer has to reduce to a minimum the interruption to traffic, while at the same time, maintaining safety at the lane change over points. The highway engineer may also be required to utilise the hard shoulder or other land adjacent to the existing highway, together with using the central reservation as a change over point; none of which are fully suitable for large volumes of traffic.

The use of precast concrete as a structural solution is a well established construction technique. The precast units are manufactured in controlled environments which ensure high quality control, economic manufacturing costs, reduced on-site congestion
and immediate site usage. The additional site advantages are that construction time is very much reduced, due to the ease of construction which is noticeable in inclement weather and the ability to reuse the raft units. However, the use of precasting for raft-type concrete pavement units has had limited application, despite the requirement to manufacture very large numbers of identical rafts.

In the past precast concrete raft pavements have been used as specialist solutions (1) such as port and container areas, where their has been high sub-grade settlements and high wheel loadings. The concrete rafts have been found to provide the required strength for the large concentrated loads and the flexibility to be reorganised and relevelled after settlement.

2. PRECAST CONCRETE RAFT PAVEMENTS - CHAPTER 2

The use of precast concrete pavement units has developed since the first published works which go back to the early 1960s (2). More recently, work concerning the use of raft units in the USA (3) and Great Britain has been published.

The range of sizes of the raft units has been considerable. They have been as small as one metre square and as large as 3.2 metres by 5.3 metres and even 2.29 metres by 10.0 metres. The aspect ratios have varied from 1 up to 18, while the thicknesses produced by various manufactures has ranged from 75 mm to 220 mm (3).

The raft units may be unreinforced and relatively thick because of the low tensile strength of concrete. The addition of steel reinforcing does not stop the concrete cracking, but it does hold the raft together after cracking and enables a thinner raft to be manufactured. The addition of fibre reinforcement in the rafts allows efficient use of materials, but at a financial cost that would not be acceptable for two metre square rafts.

The remainder of this paper will concentrate on the use of a two metre square, precast concrete, reinforced raft pavement units 150 mm thick which have been researched, over a period of years at the University of Newcastle upon Tyne (4).

The raft units are two metres square and manufactured in thicknesses ranging from 120 mm to over 200 mm. Around the top edge is a steel angle frame. Within the raft are two layers of steel reinforcement, one layer is at the top of the raft and the second at the bottom. Both the diameter and the amount of steel reinforcement can be varied. In the raft and attached to the reinforcement are two lifting holes. Research has shown (5) that these lifting holes are necessary as incorrect lifting can lead to high stresses in the raft. In the base of the raft is an octagonal recess to prevent raft creep during service.
3. THE LAYING OF RAFT PAVEMENTS - CHAPTER 3

The rafts are laid using a fork-lift truck. The sub-grade is first graded to the required profiles and falls. If the sub-grade CBR is too low then the CBR may have to be increased to reduce the amount of pavement settlement or accept that pavement relevelling may be required. Where the loading is high a granular sub-base or lean concrete layer may be required. The granular sub-base (GSB) is laid and compacted in layers. A total GSB layer thickness less than 250 mm is not recommended, due to the possibility of a raft punching through to the sub-grade. A sand bedding layer is laid, mechanically compacted and screeded to provide a complete support to the underside of the raft. The rafts are then laid, with joints between them. The joints are filled using a sand slurry or by brushing in dry sand. Edge restraints are provided to prevent the rafts moving under dynamic loads.

4. TRAFFIC LOADING - CHAPTER 4

In observing vehicles it is far easier to appreciate their physical size and gross weight rather than the individual wheel or axle-load that is more important for the design of raft units. Heavier vehicles usually have increased numbers of axles, which then reduces the individual axle-load. In general, the maximum axle-load is limited by law: in Austria, Denmark, West Germany, The Netherlands and Sweden it is 10.00 tonnes per axle; Belgium, France, Greece and Luxembourg have a limit of 13.00 tonnes per axle, while in Italy the limit is 12.00 tonnes.

In the United Kingdom the axle-loading is limited to 10.17 tonnes. To assess the different axle-load effects on road pavements, the mixed axle loadings are related through the use of the 82 kN standard axle-load. For example, a 16 tonne gross weight vehicle may be represented by 2.6 standard axles, a 32 tonne vehicle by 5.4 standard axles, and a 38 tonne gross weight vehicle by 5.1 standard axles. To relate the number of standard axles to vehicles per day it is worth noting that on such motorways as the M25 around London, flow rates of up to 70,000 vehicles per day, representing perhaps 32,500 standard axles per day are not uncommon.

5. DESIGN METHOD - CHAPTER 5

The design method takes into account the ground conditions and vehicular loadings from which the sub-base and raft requirements may be determined. The pavement life in terms of raft maintenance and raft relevelling is predictable.

The design method was developed using the finite element method of analysis, backed up by laboratory testing (5). Finite element models using up to 5285 degrees of freedom were run to provide asymptotic values for, the maximum flexural concrete tensile...
stress, used to predict the life of the raft and, the maximum sub-grade bearing pressure which is needed to predict the point at which the raft pavement will require relevelling.

The original design method was based upon the loading and sub-grade conditions found in port container areas, but when the design method is used for temporary, reusable roads, a number of simplifications are possible. The raft size, concrete strength and amount of reinforcement can be standardised as shown in Table 1. The axle-loading is related to the 82 kN standard axle and only one, two, three or four half axle-loads can be on the raft at any one time.

Table 1 : Pavement Design Parameters

<table>
<thead>
<tr>
<th>Pavement Layer</th>
<th>Basic Values</th>
<th>Fixed or Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Single and twin standard</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>82 kN axle-load</td>
<td></td>
</tr>
<tr>
<td>Raft unit</td>
<td>2m x 2m x 150 mm thick</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>50 MPa concrete</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>314mm2 steel reinforcement</td>
<td>Variable</td>
</tr>
<tr>
<td>Bedding layer</td>
<td>50mm thick</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>7.5% CBR</td>
<td>Fixed</td>
</tr>
<tr>
<td>Sub-base</td>
<td>300mm thick</td>
<td>Variable</td>
</tr>
<tr>
<td></td>
<td>20% CBR</td>
<td>Variable</td>
</tr>
<tr>
<td>Sub-grade</td>
<td>600mm thick</td>
<td>Variable</td>
</tr>
<tr>
<td></td>
<td>0.3% CBR</td>
<td>Variable</td>
</tr>
</tbody>
</table>

In Figure 1 the flow chart of the design method, which is computer based, is given. The computer assumes the pavement design parameters shown in Table 1 as a basis from which to calculate the required pavement design. The programme requests the standard axle-loading, the sub-grade CBR and thickness together with the grade of concrete to be used in the raft. Also the raft life in terms of the number of standard axle over-runs. The programme then calculates the required raft pavement design stress number (DPS) and the required design sub-grade stress number (DSS) to give the desired number of standard axle over-runs.

From the information of Table 1 the programme subtracts the DPS and the DSS values from the corresponding values of applied raft stress (APS) and the applied sub-grade stress (ASS) that would be obtained using the actual loading data. If the outputs have a zero or a negative value, then the basic pavement model of Table 1 will equal or be in excess of the required pavement life. If the results are positive numbers, then the designer knows by how much the design must be altered to achieve the required pavement...
Figure 1: Flow chart of raft pavement design method

Initial data as in Table 1

Input: Standard axle-loading
Required standard axle over-runs
Sub-grade CBR
Sub-grade depth
Concrete strength

Output: Design raft pavement stress number (DPS)
Design sub-grade stress number (DSS)

Output: Applied raft pavement stress number (APS)
Applied sub-grade stress number (ASS)

Is APS > DPS?
Is ASS > DSS?

No

Yes

Type of sub-base
1) Granular sub-base (GSB)
2) Lean concrete sub-base (LCB)

Input: GSB thickness
Input: Concrete thickness
GSB, CBR
Concrete grade

Is APS > DPS?
Is ASS > DSS?

No

Yes

Input: Raft thickness
Raft reinforcement

Is APS > DPS
Is ASS > DSS

No

Yes

Input and output record as shown in Figure 3

END
life.

The designer is now free to optimise his sub-base design. In the case of temporary roads, the sub-base may have to be imported, in which case a granular sub-base (GSB) material would be used. Alternatively, it may be necessary to use an existing lean concrete sub-base. The programme allows both options to be used, and will show the relationship between the required and achieved raft pavement life.

As it is not always possible to achieve the pavement life using a standard pavement unit, the programme will allow the amount of steel reinforcement to be altered as well as the pavement unit thickness. At this stage the programme will calculate the pavement life not only in terms of when the raft will require maintenance, but also at what point the sub-grade settlement will make relevelling of the raft pavement necessary.

A permanent record of the data input and output is printed. This allows further alteration to the design at a later date.

6. DESIGN EXAMPLE - CHAPTER 6

A highway engineer wishes to close off a section of a motorway for two days each week, over a ten week period, to effect repairs. A temporary, reusable road consisting of precast concrete rafts is to be used for those two days and moved on during the remainder of the week. Each two days 20,000 standard axles are expected to over-run the rafts. The rafts will be overlaying either a 4% CBR sub-grade, five metres thick or a 150mm thick 24 MPa lean concrete layer, overlaying the sub-grade. The highway engineer wishes to know the expected life of the rafts and the point at which sub-grade settlement will make necessary the relevelling of the pavement. It is assumed that the vehicle speeds will be reduced to a maximum of 40 km/h over the rafts.

Figures 2 and 3 show the stages of the road design.

6.1 Raft design on the 4% CBR sub-grade

Stage 1. The data input lists the expected number of standard axles that the rafts will be required to sustain over the ten week repair period. The sub-grade CBR and depth is also required. The output lists the maximum raft pavement design stress number (DPS) as 102.99 and the maximum design sub-grade stress number (DSS) as 52.96. For the rafts and the sub-grade to satisfy the highway engineers standard axle requirements neither DPS nor the DSS numbers must be exceeded.

Stage 2. Using the standard sized two metre square raft the programme calculates the standard axle loading stresses on the raft and on the sub-grade. The axle configuration that produces the maximum raft stress does not usually produce the maximum
sub-grade stress. The programme determines the difference between the applied raft stress number (APS), the applied sub-grade stress number (ASS) and the DPS and the DSS numbers respectively. Figure 2 shows that the APS number is too high by 2.76, but that the ASS number is below the required value indicating that the sub-grade strength is adequate.

Stage 3. By using a standard 150mm thick raft with 314mm2 of steel reinforcement, together with a 300mm thick layer of granular sub-base (GSB) compacted to a CBR of 30% the programme calculates the further reduction in the APS and ASS. The final values of 101.97 for the APS and 44.57 for the ASS are printed.

Stage 4. The programme calculates the number of standard axles the rafts can sustain before raft maintenance is required as 208,111. A similar calculation is made for the sub-grade which is found to be able to sustain 398,750 standard axles, indicating that sub-grade settlement will not result in relevering of the rafts during the ten week period.

Stage 5. Figure 3 lists the programme input and output for the above and the following example.

6.2 Raft design with the lean concrete layer

The first two stages of the design, are the same as in the above example.

Stage 3. Using the standard 150mm thick raft with 314mm2 of steel reinforcement as in the above and changing to the 150mm thick sub-base layer of 24MPa lean concrete which overlays the 4% CBR sub-grade, the programme will determine the final APS and ASS values, which are found to be 51.87 and 40.67 respectively.

Stage 4. The programme now calculates that the rafts will be able to carry 3,108,300 standard axles before maintenance is required and that the sub-grade settlement will make raft relevering necessary after 574,970 standard axle passes.

The use of the concrete sub-base makes possible an economy in the manufacture of the rafts. Reducing the raft thickness from 150mm to 125mm, will still enable the rafts to sustain 451,710 standard axles and the sub-grade 481,980 standard axles.

Stage 5. Figure 3 lists the data input and data output.

7. CONCLUSION

The design and use of two metre square, precast concrete rafts as temporary, reusable roads have been demonstrated. The reuse of the rafts and their easy and speedy relaying makes them a cost-effective alternative to the one use only flexible pavement, or in situ concrete materials.
**Figure 2: The stages of raft pavement design**

<table>
<thead>
<tr>
<th>Stage number</th>
<th>Data input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1) Required standard axles 200,000</td>
<td>DPS = 102.99</td>
</tr>
<tr>
<td></td>
<td>2) Sub-grade CBR 4%</td>
<td>DSS = 52.96</td>
</tr>
<tr>
<td></td>
<td>3) Sub-grade depth 5m</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1) Standard axle-load 82 kN</td>
<td>APS - DPS = 2.76</td>
</tr>
<tr>
<td></td>
<td>2) 1,2,3 or four half axles on the raft</td>
<td>ASS - DSS = -5.45</td>
</tr>
<tr>
<td>3</td>
<td>1) Raft thickness 150mm</td>
<td>APS - DPS = -3.78</td>
</tr>
<tr>
<td></td>
<td>2) GSB 30% CBR</td>
<td>ASS - DSS = -2.94</td>
</tr>
<tr>
<td></td>
<td>3) GSB 300mm thick</td>
<td>APS = 101.97</td>
</tr>
<tr>
<td></td>
<td>4) Steel area 314mm²</td>
<td>ASS = 44.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>satisfactory</td>
</tr>
<tr>
<td>4</td>
<td>1) The rafts require maintenance after 208,111 standard axle passes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) Raft releveling required after 398,750 standard axle passes</td>
<td></td>
</tr>
</tbody>
</table>
**Figure 3**: Example of computer data input and output

<table>
<thead>
<tr>
<th>Description</th>
<th>Example number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required number of standard axle</td>
<td>1</td>
</tr>
<tr>
<td>movements</td>
<td>2</td>
</tr>
<tr>
<td>Standard axle-load</td>
<td>200,000</td>
</tr>
<tr>
<td></td>
<td>82 kN</td>
</tr>
<tr>
<td>Site conditions</td>
<td></td>
</tr>
<tr>
<td>Sub-grade CBR</td>
<td>4%</td>
</tr>
<tr>
<td>Sub-grade depth</td>
<td>5m</td>
</tr>
<tr>
<td>Sub-base</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>GSB</td>
</tr>
<tr>
<td>Thickness</td>
<td>300mm</td>
</tr>
<tr>
<td>CBR/compressive strength</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>concrete</td>
</tr>
<tr>
<td></td>
<td>150mm</td>
</tr>
<tr>
<td></td>
<td>24MPa</td>
</tr>
<tr>
<td>Raft</td>
<td></td>
</tr>
<tr>
<td>Concrete strength</td>
<td>50MPa</td>
</tr>
<tr>
<td>Size</td>
<td>2m x 2m</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>314mm²</td>
</tr>
<tr>
<td>Thickness</td>
<td>150mm</td>
</tr>
<tr>
<td></td>
<td>150mm</td>
</tr>
<tr>
<td></td>
<td>125mm</td>
</tr>
<tr>
<td>Achieved standard axle movements</td>
<td></td>
</tr>
<tr>
<td>1) Before the raft requires maintenance</td>
<td>208,110</td>
</tr>
<tr>
<td></td>
<td>3108300</td>
</tr>
<tr>
<td></td>
<td>451710</td>
</tr>
<tr>
<td>2) Before raft relevelling is required</td>
<td>398,750</td>
</tr>
<tr>
<td></td>
<td>574970</td>
</tr>
<tr>
<td></td>
<td>481710</td>
</tr>
</tbody>
</table>
Further research is proceeding into the design and use of other rectangular shapes.

8. ACKNOWLEDGEMENTS

This research is supported by SERC Grant No. GR/B/86101 and Redland Aggregates Ltd, Redland Precast Division, UK.

9. REFERENCES


