NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 27

PCC PAVEMENTS FOR LOW-VOLUME ROADS AND CITY STREETS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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

AREAS OF INTEREST:
PAVEMENT DESIGN
CONSTRUCTION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1975

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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

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The members of the advisory committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the advisory committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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PREFACE

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

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

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to state and local highway officials, design and construction engineers, and others who may wish to consider the portland cement concrete pavement alternative for rural highways and city streets that are to serve low volumes of traffic. Detailed information is offered on planning, designing, and constructing portland cement concrete pavements for light traffic conditions, based on experience accumulated during the past 20 years by a number of agencies that have used this type of pavement for low-volume facilities.

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

Portland cement concrete pavement has been looked upon historically as premium pavement for use principally where high volumes of traffic are to be expected. Structural design criteria, construction equipment and processes, and material uses that have been developed over the years for concrete paving have been oriented toward this use. Low-volume roads and streets usually have been constructed of less costly materials and by less expensive processes. Often, no higher standards are justified; and, always, this will place a greater mileage of pavement in service more quickly. Sometimes, however, a consideration of future maintenance costs and rehabilitation needs may suggest that a higher-quality pavement will be the more economic alternative on an annual cost basis. Over the past several years, a growing number of agencies has seen a potential for portland cement concrete pavement serving economically in selected low-volume situations. These agencies have developed ways of reducing original cost to where concrete seems to be an economically competitive material under some circumstances. Locations where traffic patterns are not likely to change over many years, or where relatively thin overlays cannot be expected to upgrade existing pavements to provide comparable service, are seen to offer the best opportunities for economical use of concrete for low-volume roads and streets.

This report of the Transportation Research Board describes and assesses the merit of current practice in the use of portland cement concrete for low-volume roads and streets. Information is presented on the factors to be considered in planning the low-volume pavement project, and on designing and constructing portland cement pavements for low-volume use. Research needs in the area are identified.

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

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

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Information on current practice and ongoing research was provided by many highway agencies, contractors, and others concerned with PCC pavements for low-volume roads and city streets. Their cooperation and assistance were most helpful.

PCC PAVEMENTS FOR LOW-VOLUME ROADS AND CITY STREETS

SUMMARY

A major concern of every highway administrator is the adequate funding of construction and maintenance work needed on roads and streets under his jurisdiction. The more heavily traveled routes usually generate sufficient funds from highway user charges to cover the cost of their own improvements and upkeep. However, the cost of low-volume traffic facilities is difficult to justify in relation to the benefits or services they render.

Of the 3.2 million miles (5,150,000 km) of rural roads and 614,000 miles (990,000 km) of municipal streets in the U.S., approximately two-thirds carry less than 400 vehicles per day. Because of the extensive mileage involved, a substantial amount of funds is required to keep these facilities operating satisfactorily. It also means that almost every state and local highway administrator in the country has to make critical decisions regarding management of these roads and streets. The public demand for a reasonably good level of service on low-volume facilities complicates the problem.

The alternatives available to administrators of low-volume facilities are: (1) to secure an increased allocation of funds for improvements and maintenance under present methods; (2) to select the type of improvements that will best balance construction costs and maintenance costs in order to ensure a lower, long-range, average annual cost; or (3) to persuade the using public to accept a lower level of service. Although all three alternatives can be used to some degree, alternatives (1) and (3) have their limitations.

Highway agencies in several states and cities have accumulated experience in the past 20 years in the use of portland cement concrete (PCC) pavement specifically designed and built for low-volume facilities. Aided by interested contractors and equipment manufacturers, standards have been developed, equipment produced, and construction techniques devised, all of which have helped lower initial construction costs of these pavements. Experience to date indicates that PCC pavement has a good probability of maintaining extremely low maintenance costs and a satisfactory level of service over a long period. This synthesis is intended to make this experience available to others who desire to explore the possibility of using PCC pavements.

The most promising routes for this type of improvement are those whose traffic patterns are not likely to undergo major changes over a period of many years. These are primarily low-volume facilities with little probability of developing into cutoff or bypass routes. Neither are they likely to experience major changes in adjacent land use that would result in major increases in traffic, particularly trucks. The low-volume nature of such roads allows the use of pavements having lower structural safety factors than usual, which helps reduce costs.

The adoption of uniform standards for this type of construction stimulates competition among contractors, encourages investment in the most productive type of equipment, and results in the development of construction techniques that keep costs down while producing a quality product.

The use of local aggregates and exploration for new sources should be encouraged. Low-cost advantages of using local aggregates include blending to produce acceptable gradings and modifying specifications to use local materials without any substantial sacrifice in the quality of the concrete.

Performance data and soil surveys are needed to plan for treatment of soft spots and frost boils. Uniformity of the subgrade can be obtained by blending, replacement, stabilization, incorporation of existing granular materials, scarifying, and compaction of the subgrade. Pavements on a subgrade with uniform support can be designed with a low margin of structural safety and still ensure satisfactory performance for many years of low-volume traffic.

Experience with substantial mileage of low-volume roads and city streets has demonstrated that a consistent quality concrete pavement can be produced and placed at a practical cost, which when averaged with low annual maintenance costs results in a low average annual cost.

The success of PCC pavements for low-volume roads and city streets depends on good engineering judgment throughout the planning, design, construction, and maintenance stages. Careful consideration must be given to reliable projections of future traffic, analysis of soil conditions, corrective measures to ensure uniform subgrade support, adequate pavement design for the anticipated traffic, good quality control during all construction phases, and management procedures that permit a high production rate. In-depth studies, good judgment, and timely management decisions are necessary steps in achieving the objective—a low-cost pavement with a minimum of maintenance and a good level of service.

CHAPTER ONE

INTRODUCTION

GENERAL SITUATION

In the United States, approximately 80 percent of the total vehicle-miles of travel occur over only 20 percent of the total highway mileage (including both rural and urban roads). Conversely, only about 20 percent of the vehicle-miles of travel occur over the remaining 80 percent (Fig. 1). Of the 3.2 million miles (5,150,000 km) of rural roads and 614,000 miles (990,000 km) of municipal streets in the United States in 1972, a major portion consists of low-volume traffic facilities carrying less than 1,000 vehicles per day (average daily traffic—ADT) and nearly two-thirds of the total mileage carries less than 400 ADT. Although these low-volume roads and streets are important to their users, they create a major financial problem for the highway agencies responsible for providing adequate service at a cost that can be financed.

Roads and streets with high volumes of traffic can be financed by the highway-user funds they generate, but low-volume roads cannot. Moreover, low-volume routes cannot be scaled down proportionately in terms of cost and service offered in order to be self-supporting because users expect a reasonably good level of service. It is generally accepted that low-volume roads and streets must be subsidized by highway-user funds produced by high-volume facilities or by other funds, such as property taxes or special assessments related to the value of good land access. The cost of these many miles of low-volume roads and streets has caused difficult economic and political problems on all levels of government. For these reasons, particular attention is being given to improving the technology relating to these low-volume facilities. The pavement represents a substantial portion of the costs of highway construction and maintenance. It also is the principal element of the roadway that determines the level of service provided to the highway user. The highway engineer is challenged to develop a pavement that will give an acceptable level of service for low-volume facilities at an annual cost that can be justified.

There are two classifications of low-volume roads and streets (Table 1) to be considered in the search for an acceptable pavement type. Group 1 requires consideration of how best to protect and use the existing investment when making an improvement. Group 2 demands a careful study in order to identify the type of improvement that can be financially supported and still give an acceptable level of service.

For some years, the desire for improving the technology of low-volume pavements has directed attention to the use of concrete as a paving material for these facilities in order to satisfy both the long-range-cost and level-of-service criteria.

Development of Concrete Pavements for Low-Volume Roads and Streets

In the early part of this century, concrete was used in some areas to pave lightly traveled roads and streets. At that time, several counties in Illinois built considerable mileage of one-lane concrete pavements on their secondary road system. Many of these pavements are still serving traffic either as surface or as base. Other states followed a similar pattern, and a number of cities used concrete to pave their residential streets, which are still in service. Although some agencies have continued to use concrete for local roads and streets, concrete pavement standards and specifications were developed primarily for the more heavily traveled routes for several decades. Increases in the cost of labor and materials as well as the development of high-production-capability construction equipment have limited the use of concrete mostly to the primary routes. Meanwhile, the agencies responsible for the large mileage of secondary and local roads and streets were striving to achieve an all-weather surface by using the most readily available local materials. The use of gravel surfaces with local aggregate was necessary in order to complete as many miles as possible with limited funds. But the motoring public gradually began to expect surfaecs that were dustless and which would accommodate higher speeds, even on low-volume roads. Some of the surfaces provided to meet a desired level of service were inadequately designed and poorly constructed, which contributed to ever higher maintenance costs.

After World War II, increased motor vehicle travel and the growing desire of highway users for a better level of service from all roads and streets stimulated interest in developing a pavement that could be built at a relatively low initial cost, but which would have a long life and low annual maintenance cost. The objective was a pavement capable of providing a service level acceptable to users at an annual cost that the highway agency could afford.

In its search for a solution to this problem, Greene County, Iowa, in 1951 built two miles of portland cement concrete (PCC) pavement with sections 4½, 5, and 5½ in. (114, 127, and 140 mm) thick. The condition of this pavement in 1970 is shown in Figure 2.

A 1968 performance evaluation of this pavement, which had been carrying over 400 vpd for 17 years, indicated that it was in good condition because it rated a present serviceability index (PSI) of 3.7 on a standard scale of 0 to 5. There was little difference in the performance of the three sections.

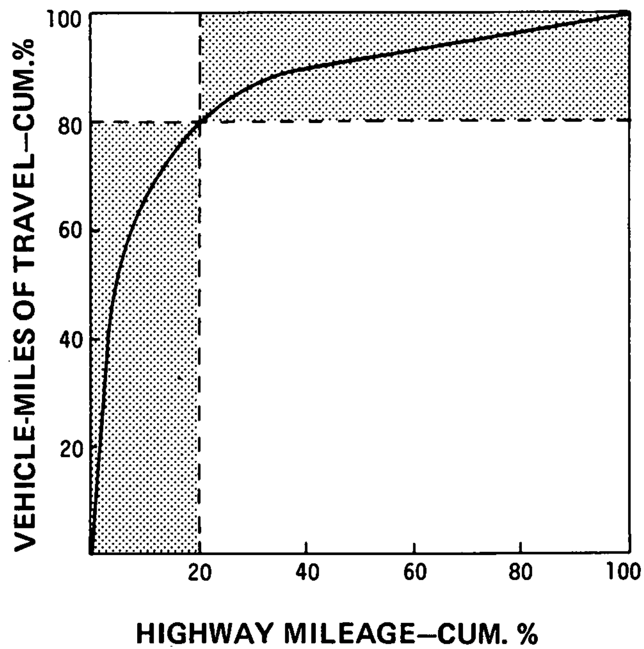

Figure 1. Distribution of vehicle travel on highway mileage.

In 1954, Greene County built the first section (2 miles; 3.2 km) of slip-form paving in the country, and has since paved over 150 miles (240 km) of its road system with concrete using the slip-form method. Other Iowa counties became interested, and, to date, 79 of the 99 counties have used concrete pavement for new construction. More than 3,000 miles (4,800 km) of concrete pavement built over a 22-yr period are currently in service on the Iowa secondary road system. Ninety percent of these plain concrete pavements are 6 in. (150 mm) thick, 8.5 percent are 7 in. (175 mm) thick, and 1.5 percent are 8 in. (300 mm) thick. The average daily traffic (ADT) on most of these pavements is between 200 and 2,000.

In 1971, Nebraska had 130 miles (210 km) of 6- and 7-in. (150 and 175 mm) pavement on its secondary road system and Minnesota had 35 miles (56 km) of 6- and 6½-in. (150 and 160 mm) pavement on its county road system. Illinois has recently revised its standards to permit the use of 6- and 7-in. plain concrete with no base on low-volume traffic facilities (Fig. 3). Other states have moved in this direction.

TABLE 1

CHARACTERISTICS OF LOW-VOLUME ROADS AND STREETS

GROUP 1	GROUP 2
Existing low-cost pavement	Unpaved
High maintenance costs and resultant financial drain	Lowest traffic volumes
Inadequate level of service	Inadequate level of service

Figure 2. PCC pavement after 19 years' service. Background thickness (beyond intersection) is 5½ in. (140 mm) nonreinforced; foreground thickness is 5 in. (127 mm) nonreinforced.

Figure 3. Example of an Illinois low-volume county road built using 6- and 7-in. plain concrete with no base.

The development of the slip-form paver, central mixing plant, and automated fine-grading equipment has made concrete competitive with other materials for use on low-volume rural roads. This equipment is not ideal for small project contracts or for city streets having utilities in the way as well as numerous cross streets. Nevertheless, there has been a growing trend to develop ways of using concrete economically for low-volume streets in order to lower long-term maintenance costs. As a result, a number of cities are now paving low-volume streets with concrete (Fig. 4).

Figure 4. Example of low-volume residential street paved with concrete having integral curb and gutter.

Factors Influencing a Decision to Use Concrete

The engineering challenge is to design and build for low-volume facilities a concrete pavement that will meet the requirements of low initial cost, good performance over a long life span and low annual maintenance costs.

The initial cost is influenced by the design standards, the specification requirements, and the construction techniques. The standards, specifications, and techniques must be adjusted to the specific needs of low-volume facilities to eliminate every nonessential cost item and, at the same time, must ensure good performance during the design life. The secret of success is to design and build each project according to its specific conditions and individual requirements (*1*).

Good performance is measured by smooth riding quality, high skid resistance, high degree of night visibility, relatively few patches and holes, and a minimum of interference with traffic flow by maintenance work. Good performance for many years is dependent on proper design, quality control in construction, and adequate maintenance.

Low maintenance costs result when a pavement is properly adapted to the conditions under which it is to serve. Many design decisions directly affect the amount of maintenance that will later have to be performed. A pavement that is underdesigned for its traffic and exposure conditions will give poor performance and have high maintenance costs.

The proper balance of initial costs and maintenance costs will give a low average annual cost over many years along with an acceptable level of service.

PURPOSE AND SCOPE

During the past 20 years, a number of individuals and organizations, principally in Iowa and adjoining states, have become interested in the use of concrete pavement for low-volume roads and streets. Many miles of such pavement have been built and much experience with these pavements has been acquired by state, county, and city engineers; consultants; contractors; equipment manufacturers; and materials organizations. The purpose of this synthesis is to report the results of this experience so that everyone interested in low-volume roads and city streets may use this knowledge in decision-making.

The scope of this synthesis is limited to PCC pavements for low-volume roads and city streets. It is not intended to be a treatise on the broad subject of concrete pavements for all uses, although many of the items covered may be related to other uses. Furthermore, the synthesis does not include detailed technical information and procedures that are adequately described in the literature cited as references and which are available to interested persons.

CHAPTER TWO

PLANNING THE PAVING PROJECT

In planning a paving project, the major decision is the type of pavement to use. All of the factors discussed in this chapter may have some bearing on the selection of the pavement type and should be considered. Some of these factors influence the decision much more than others. The responsible engineer analyzes these factors and uses his knowledge and experience to select a pavement that will have a competitive initial cost, a long service life, and low annual maintenance costs. Highway engineers and contractors must continue to work together, as they have in the past, to achieve those objectives.

TRAFFIC

Because the total axle loads as well as the number of vehicles that use a pavement have a major influence on the performance of that pavement, the traffic to be expected over the life of the pavement is a critical element in the planning process. The emphasis in good planning must rest on a reasonably reliable forecast of the traffic that will use the pavement over its projected design life. The objective is to look closely and specifically at each project. This should not be a generalized approach, although general statistics from many sourecs may be helpful. Consideration should be given to:

- Current traffic data.
- Location of the project in the existing road or street system.
- Probability of rerouting traffic because of work on the route under consideration or on nearby routes.
- Possibilities of commercial or industrial development along an improved faciilty that might affect traffic projections.
- Possible changes in business practices that might increase maximum loads.
- Need for seasonal or other maximum weight restrictions.

Reliable predictions can be made for most projects. The application of good judgment by an experienced highway engineer to these considerations will determine whether general projection factors should be used or whether they should be modified to fit the project under consideration. This critical review of the traffic projections for each project, whether it be a rural road or a city street, is essential for proper selection of pavement type and for other planning and design decisions.

The proper functional classification of any road or street is essential in order to reliably predict its use and determine its adequate and economical design. A great amount of experience has been acquired in the functional classification of road and street facilities into groupings (arterials, collectors, and land access routes, each of which has various subgroupings) according to the principal purpose they are to serve. These facilities range from primaries having high-speed, uninterrupted flow to secondary and rural roads providing basically land access.

It is desirable to define numerically what is meant by "low-volume" roads and streets. For many uses, low volume is only a relative term depending on the surrounding conditions. One public works director in a large metropolitan area suggests 10,000 ADT as the break point for low-volume traffic on city streets. Another person in a similar position suggests 8,000 ADT. Still others consider low-volume street traffic to be under 500 ADT. Similarly, the suggested dividing line for rural roads varies from 2,500 ADT to 200 ADT. However, within the limits of these extreme ranges, general agreement exists that, for the purposes of this synthesis, low volume means under 1,000 ADT, with up to 30 percent commercial vehicles and up to 15 percent heavy commercial (over four tires), and with very few vehicles over 18,000 lb (8,000 kg) on a single axle or 32,000 lb (14,500 kg) on a tandem axle. No weight restrictions, other than legal limits, are imposed on either rural roads or city streets in the planning process. Rural roads in this category are farm-to-market and land access roads with design speeds up to 55 mph (90 km/hr). City streets in this category are collectors and residential streets with design speeds of 25 to 40 mph (40 to 65 km/hr).

SUBGRADE CONDITIONS

Many miles of PCC pavement design for low-volume traffic have been built on A-6 and A-7-6 soils with high index numbers. Some agencies report that all of their subgrades are in the A-7-6 classification. Several comment that, although PCC pavement performs better on a stable subgrade, it has an advantage on soft subgrades because of its bridging action. However, some would not use PCC pavement with unstable and saturated subgrades. Pumping usually is not a problem because of the smaller number of heavy vehicles. A California bearing ratio (CBR) of 3.5 to 4 has been suggested as a desirable minimum, and compaction of the subgrade to achieve a uniform high density is recommended. In-place granular materials should be incorporated in the top of the subgrade whenever practical. Drainage improvements that would help the subgrade should be included in the plan.

Frost boils have been treated by drainage and by removing and replacing the frost-susceptible materials. Although excellent results are reported with the use of insulation on the subgrade over the boil areas to prevent freezing, much concern exists because the roadway surface over insulation freezes sooner. Some blending of soils to improve uniformity and compaction on the wet side of optimum has been tried in order to avoid differential movement, which occurs with changes in moisture in soils subject to high-volume changes.

EXPOSURE ELEMENTS AFFECTING PERFORMANCE

As a part of planning, attention must be given to the principal exposure elements of precipitation and temperature that affect pavement performance. Also included are the number of cycles of freezing and thawing and the amount of deicing chemicals and abrasives likely to be used on the pavement. Special attention to the pavement may be warranted at intersections and on curves and hills where larger amounts of deicing materials might be used, thus traffic abrasion will be greater. More careful attention to air entrainment and proper curing will be needed where exposure to deicing materials is high. It is good engineering practice to plan the project for the actual exposure elements to which a particular pavement is likely to be subjected. If this is not done, performance of the pavement may fall far short of the engineer's estimate.

MATERIALS AVAILABILITY

Planning includes an investigation of all possible sources of materials, particularly aggregates, near to the project. This is because transportation is a substantial part of materials costs. Current cost data indicate a haul limit of 25 to 35 miles (40 to 56 km) for aggregates in order to keep the pavement cost reasonable. Highway and other public agencies and testing laboratories have accumulated much data on the location and properties of paving aggregates. However, in many areas much more investigation and testing is needed to find local materials. The possibilities of processing local materials or blending them with other materials to improve the quality to an acceptable standard should be considered. Specification modifications may be justified to permit satisfactory use of materials more economical for the job. Both the concrete mixture proportions and the selection of slab thickness may be modified to allow the use of more economical local materials.

The characteristics of the available local materials also need to be evaluated to determine which pavement type can use these materials to the best advantage. Some coarse limestone aggregates have a tendency to cause "D" cracking in concrete pavement. In some areas, local sand-gravel aggregate can react with the alkalies in the portland cement and cause map cracking. Where local materials are questionable, it may be more economical to import higher-quality aggregates that will give longer service. Adjustments to the mixture proportions and the use of low-alkali cements can also compensate somewhat for low-quality aggregates. This is another situation where good engineering judgment and experience are needed in the planning of each project to find the optimum solution while considering cost and performance.

UTILITIES IN THE PAVEMENT AREA

Rural roads usually have few utilities situated near the pavement, whereas city streets often have a number of utilities that affect project planning. It is common practice to place utilities outside the pavement to facilitate their continuing maintenance and potential additions thus avoiding future pavement cuts and backfill settlement. Sanitary sewer connections and water and gas line leads may cross under the pavement. Manholes, valve vaults, and catch basins may project to the top of the pavement where there are connecting lines underneath. It is good practice to coordinate with utility organizations early in the planning phase for a paving project. This contact may enable the utility agencies to improve their locations and to avoid pavement cuts after the project has been completed.

Utilities, either existing or anticipated, can affect the planning for the pavement in a number of ways. Utility trenches will contribute to differential subgrade settlement unless they are carefully backfilled and compacted. It is good practice to have an inspector present when the backfilling is done. Utilities should be designed and placed so that they will not be damaged by backfilling or other construction activity. If any portion of a utility projects above the subgrade, it will interfere with subgrading operations and, particularly, with the use of automated fine-grading equipment. Care must be used in placing the paving material around the utility. Compaction is difficult and special hand work is required in finishing, which add to the pavement cost (Figs. 5 and 6). Surface smoothness is sacrificed because it is difficult to match the pavement surface to fixed objects.

Any subsequent excavation under the pavement or cuts through the pavement for the purpose of installing, maintaining, or repairing utilities can affect the maintenance costs of the pavement and its riding quality unless the work is most carefully done. In cases where utility connections need to pass under the pavement, the possibility of jacking

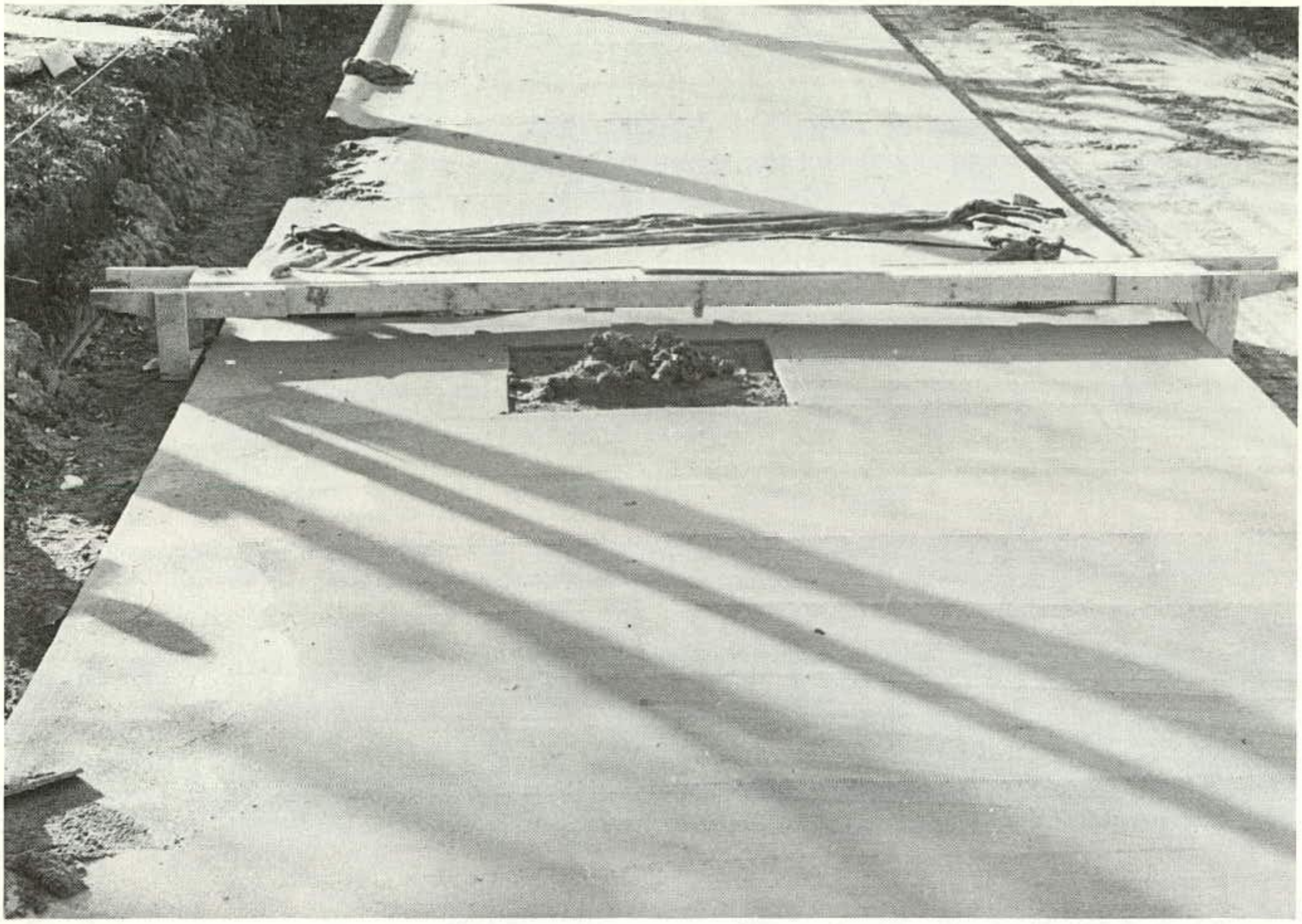

Figure 5. A city street being slip-form paved. Readily visible are the integral curb, block-outs for inlet and manhole, and curb removal at the intersection.

the line under the pavement should be explored. If the pavement must be broken, saw cuts should be used. Good backfill material, properly compacted, is essential. When these cuts are made at will by the utility companies, the absence of inspectors often leads to a poor job. The finished surface of the patch almost never matches the surrounding pavement.

When the pavement needs resurfacing, utilities at the surface require either that they be raised to the level of the new pavement or that the new pavement be sloped around them, which results in a bump in the pavement. The first choice is costly; the second is highly undesirable because of reduced riding quality. The available options emphasize the desirability of running utilities elsewhere than under the pavement whenever possible.

Except for the specific points made previously, there is general agreement that the presence or absence of utilities has little or no effect on the decision as to what type of pavement to use for a low-volume road or street.

EQUIPMENT AND CONSTRUCTION EXPERTISE

Much of the credit for the increased use of PCC pavement for low-volume rural roads during the past 20 years must be given to those who developed the slip-form paver, the central mix plant, and the automated subgrader (Figs. 7, 8, and 9). Equally important is the effective use of this equipment in order to achieve both a high rate of production and good quality control. The 3,000 miles (4,800 km) of PCC pavement built on the county secondary road system in Iowa during this period testify to these improvements. Iowa's roughometer data show a marked improvement in the riding quality of slip-form pavement over pavement built with forms (*2, 3*).

One study shows that, between 1967 and 1971, the use of such equipment doubled the number of square yards of concrete laid per day and cut the labor cost per square yard by 50 percent (*4*). An Idaho study indicated that the cost of concrete pavement was reduced by nearly 50 percent over a six-year period by the use of this equipment (*5*). With proper planning of the low-volume project as to size and construction methods, the equipment developed for use on state projects often can be used either as is or with some modifications.

Because the equipment is quite expensive and requires time to train personnel in its efficient use, these improvements are available only where an effort is made to encourage contractors to own such equipment and develop the skill to use it. Motivation of this type requires the develop-

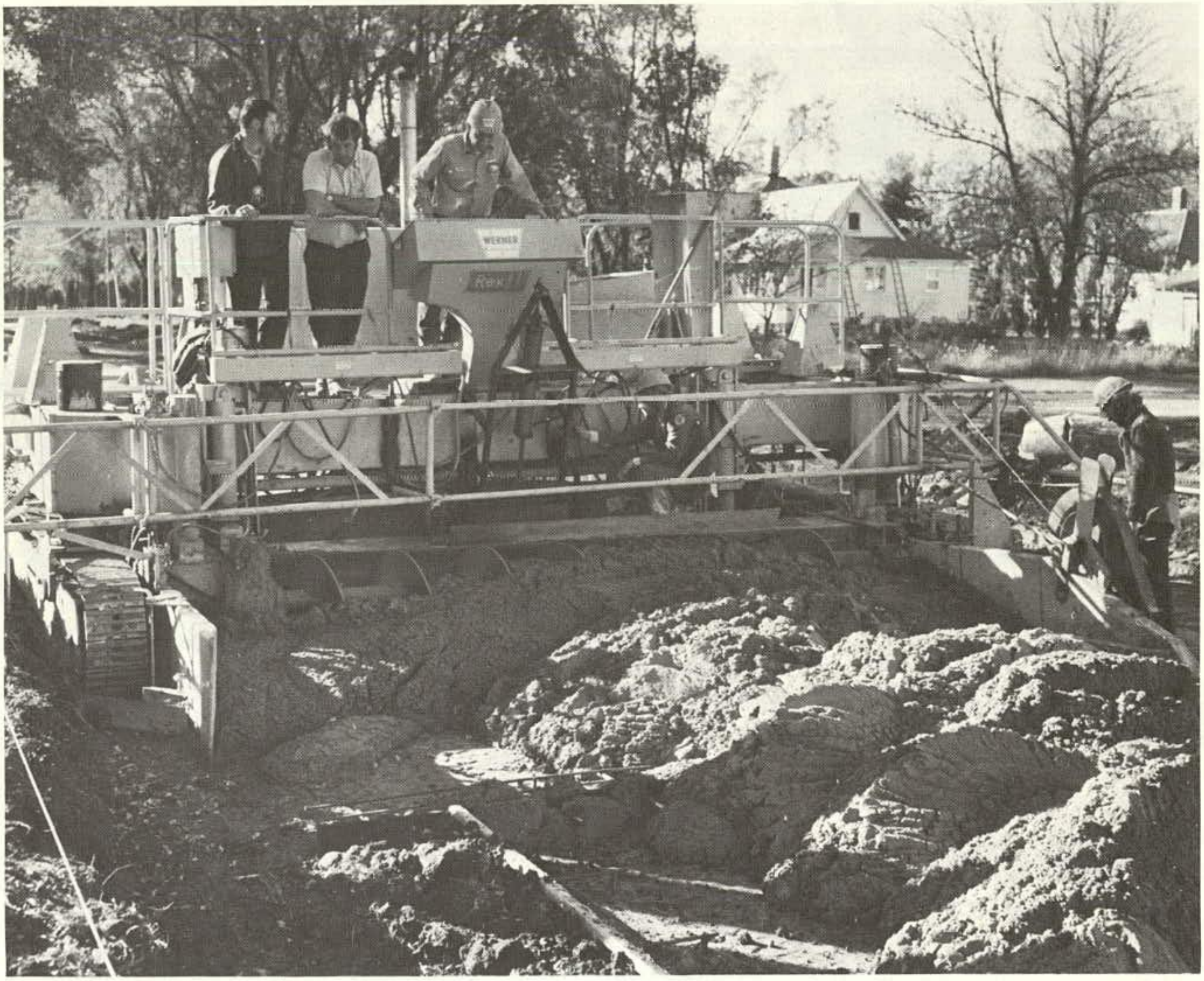
Figure 6. Slip-form paving a city street. Visible is the inlet to a catch basin, including the tie bars.

ment of specifications that standardize construction for a number of neighboring agencies. Standardization, in turn, encourages more contractors to bid on work, increases their competition, and results in better prices. Reasonable uniformity in common specifications facilitates economical use of the equipment and the development of the best operational and management techniques.

Larger-size projects also help lower unit cost. The high-production equipment and methods used on rural road concrete paving projects are not generally applicable to low-volume city street paving unless project sizes are specifically planned for this type of construction. Low-volume street projects are often short, involve utilities in the pavement, and encounter intersections and driveways, all of which limit the use of the costly high-production equipment. However, city engineers and contractors have used ingenuity in developing standards, specifications, and construction techniques that make use of the best of smaller modern equipment to build concrete pavements of good quality at competitive prices.

PAVEMENT DESIGN LIFE

Because traffic analyses and cost considerations must be correlated with the projected life of the pavement, some definition of design life is required. A study of PCC pavements of all classes in 19 states indicates an average service life of 25 years (*6*). Design lives of 20 to 40 years for concrete pavements are used by some agencies and are not uncommon for roads and streets in the low-volume category. Design life, as used herein, is defined as the length of time from construction to the point where the pavement reaches a terminal serviceability level. It is essential during planning to consider carefully the reliability of estimates of future traffic volumes and the possibility of heavier vehicle loads. Facilities that have a low probability of any significant variation from the traffic projections are much better choices for cost-cutting designs than are others that may have to be upgraded before the end of the anticipated design life. Good engineering judgment must be applied to make this determination for each particular project.

Figure 7. Slip-form paving a city street with integral curb.

PAVEMENT COSTS

Economic studies indicate improvement costs for low-volume roads and city streets must be kept at a reasonably low level to be justified. However, a lack of specific data as to costs and benefits limits the accuracy of studies in this area. Because economic justification is often marginal, great effort is necessary to minimize both construction and maintenance costs for such projects. Requiring low-volume roads or city streets to fit the needs usually associated with major highways or streets results in overdesign and excessive cost.

The prime objective is to obtain the lowest possible aver-

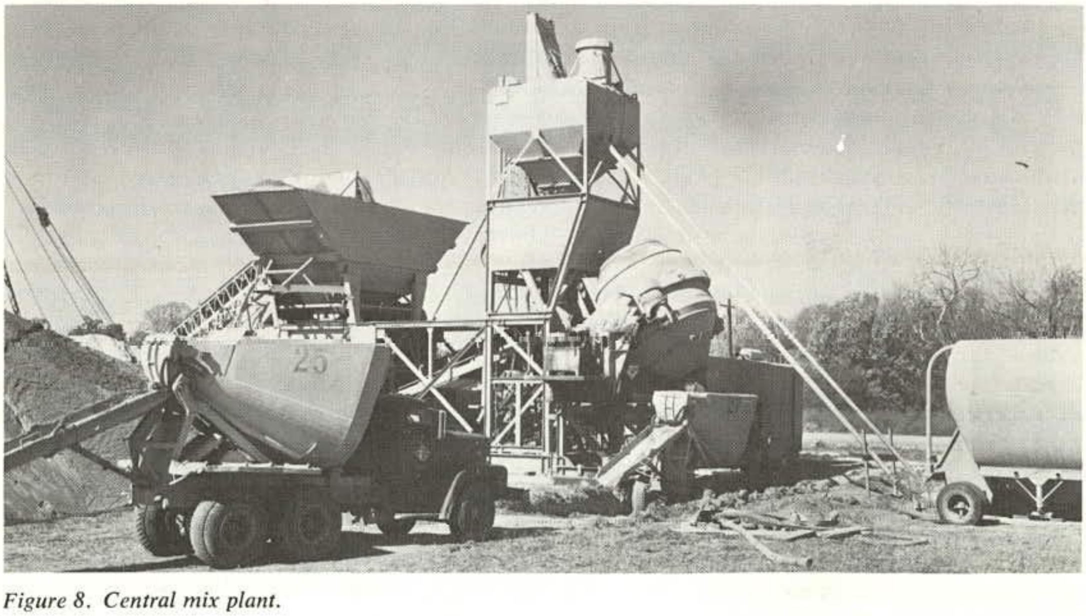

Figure 8. Central mix plant.

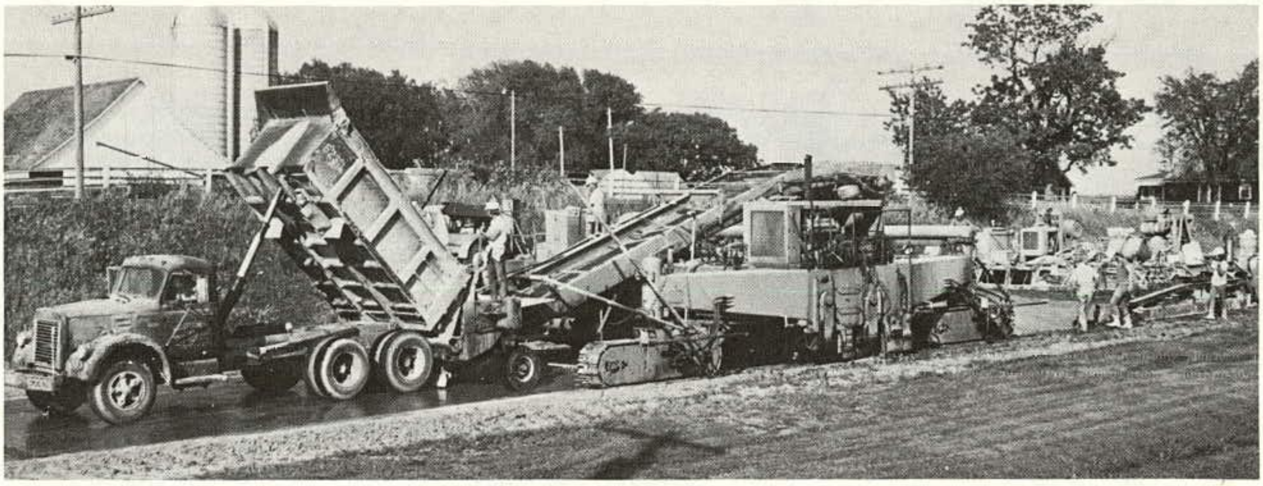

Figure 9. "Iowa special" with belt conveyor to carry concrete over the fine-grader to the slip-form paver.

age annual cost over the pavement life commensurate with an acceptable level of service. This requires a balancing of the cost of:

- Initial construction.
- Maintenance.
- Accidents (pavement-related).
- Traffic interruptions (for maintenance, resurfacing, or reconstruction operations).
- Load restrictions.

These costs are distributed over the life of the pavement. Low annual cost and good pavement performance are the true measures of engineering effectiveness.

In the 1950's, a program was initiated in Iowa emphasizing the construction of secondary roads to minimize maintenance costs. There was a concentrated search by highway agencies for ways of reducing construction costs, upgrading pavement quality, and reducing high annual maintenance budgets. To improve their competitive position, highway contractors were attempting to improve their operational efficiency, to increase production capacities, to reduce capital equipment investments, and to reduce overhead expenses. According to one county engineer, "they were searching for a type of construction for low-traffic roads that the counties could afford to own."

The Iowa State Highway Commission has developed standards for high-quality but simply built roads for low-volume traffic. Most of these were built with automated construction equipment on existing grades, using on-site soil for subgrade. Up to 1970, the five Iowa counties with the oldest PCC pavement were averaging maintenance costs of $20 per mile ($12/km) per year (*4*). They have demonstrated that, for low-volume traffic, relatively low-cost 6-in. (150 mm) plain concrete pavement with low maintenance cost and good performance can be built on poor-quality subgrades with severe freeze-thaw conditions.

Information from some city engineers and public works directors indicates similar results for construction and maintenance costs for low-volume streets, although automated equipment was not generally used. Low maintenance cost over a long life span has strong influence on the decision to select PCC pavement.

PAVEMENT SERVICEABILITY AND PERFORMANCE

Since the AASHO Road Test, two terms are used to define pavement condition: (1) "pavement serviceability," meaning the ability to serve traffic, and (2) "pavement performance," meaning the level of serviceability over a designated period of time. Pavement serviceability is expressed as the present serviceability index (PSI) on a scale of 0 to 5, the poorest to the best, respectively. Terminal serviceability, or the level at which resurfacing or some other action must be taken to upgrade the service level of the pavement, usually occurs at about 2 or 2.5 for low-volume roads.

Good serviceability implies good skid resistance, smooth riding surface, absence of loose materials, good visibility under adverse conditions, acceptable effect on tire wear, low noise level, suitable appearance, and minimized interference with traffic flow from maintenance, resurfacing, or reconstruction operations for the design life.

A 1968-69 study of 95 percent, or 2,044 miles (3,300 km), of the concrete pavement constructed on Iowa secondary roads between 1955 and 1969 showed a range of PSI from 3.26 to 4.15 with a weighted average of 3.91 (high in the good category) (*7*). In 1970, these pavements were carrying mixed traffic varying in volume from 200 to 2,000 ADT. In Iowa, the riding quality of slip-form paving improved from 98 in. of roughness per mile (1,550 mm/km) average in 1955 to 73 in. per mile (1,150 mm/km) in 1969. This was due to improvements in both equipment and construction techniques. The study of pavement performance in relation to the contractors' operations gave an indication that the contractors' equipment, knowledge, and proficiency might account for the upward slope of the performance trend curve more than the effects of pavement age and traffic (*7*). Measured data are scarce on performance of concrete pavement on low-volume streets, but there are numerous examples of old pavements that are still giving excellent service with little maintenance.

Performance studies on the lighter-load traffic loop of the AASHO Road Test indicated that relatively thin sections of concrete pavement could give good performance with little maintenance under traffic conditions similar to those on the test loop.

Good performance is closely related to low maintenance costs for most low-volume pavements and both are considered in the planning process.

PROJECT SIZE, COST, AND FUNDS AVAILABLE

As indicated earlier, an increase in the size of a project usually decreases the unit construction costs. However, the funds available to a highway agency at any given time limit the size of the projects that it may undertake. Careful planning may make it possible to undertake fewer but larger projects in any given year in order to get more for the money spent, rather than undertake numerous small projects. Iowa met this problem years ago by grouping all of its secondary roads into single county unit systems, which gives greater flexibility in financing, permitting larger projects and more detailed engineering studies. A deterrent to planning the most economical size of improvements is the political pressure to spread the money available over the entire area of agency responsibility.

CHAPTER THREE

DESIGNING THE PAVEMENT

GENERAL BACKGROUND FOR DESIGN

General guidelines exist that are helpful to the pavement designer. First, the physical characteristics required of any pavement to provide acceptable performance for a reasonable design life include:

- Suitable geometrics, such as satisfactory horizontal and vertical alignments and roadway cross section.
- Adequate internal stability to keep distortion of the surface within tolerable limits.
- Ability to distribute pressures to the subgrade that will keep deformations under wheel loads within acceptable limits.
- Resistance of the surface to the wear of traffic and the deteriorating effects of weather and chemical action.
- Resistance to the effects of internal forces such as expansion, contraction, and warping.
- Limits in load-carrying capacity induced by exposure elements.

Specific attention should be given to such factors affecting performance and service life of a PCC pavement as:

- Stability of underlying soils with regard to frost and moisture volume change.
- Quality and uniformity of embankment and pavement sublayers.
- Water saturation of area beneath pavement.
- Need for control of pumping action.
- Quality and thickness of concrete sufficient to control stresses and deformation.
- Type and spacing of joints and load transfer to minimize excessive stress levels.
- Weathering and exposure conditions.
- Unexpected severe overloadings.

Finally, the prime design considerations are:

- Anticipated traffic for desirable service life including total number of vehicles and axle load distribution on the heavier vehicles.
- Subgrade strength and uniformity.
- Concrete properties.

DATA DEVELOPMENT

Before decisions can be made concerning the specifics of the pavement design, certain data must be developed.

Traffic Characteristics

Much emphasis is placed on the importance of reliable estimates of traffic, including predictions on the distribution of axle loads. The final data are expressed in terms of number of vehicles and the axle load distribution during the selected design life of the pavement. Volume is usually expressed as average daily traffic (ADT), and axle loads can be expressed in numbers of 2,000-lb (900 kg) increments for both single and tandem axles—Portland Cement Association (PCA) method—or as equivalent 18-kip (8,200 kg) single-axle loads—American Association of State Highway and Transportation Officials (AASHTO) method.

The prediction of traffic for design must rely on accumulated traffic data modified by growth factors or other changes. Volume data can be obtained from staff field counts; from state, county, or city traffic maps or traffic survey reports; or from urban area transportation studies. This is followed by the application of projections either based on past statistics from tables for area and functional classification projections or based on the knowledge and experience of the agency engineering staff.

Most states accumulate loadometer data in the format of the Federal Highway Administartion W4 loadometer tables, but many of these data are for primary routes. Therefore, low-volume roads and streets, being more individual in character, may have few data on which to base estimates. Local agencies usually must prepare their own data. Some probability constants of load distribution for various classes of roads and streets, which were developed by Robbins and Warnes (*8*), can be used in predicting axle-load distributions when more accurate data are not available.

Subgrade Soil Conditions

The ultimate performance of the pavement depends on the quality of information on subgrade soils and how it is utilized in the design. Usually not enough engineering effort is expended in gathering and evaluating soil data for low-volume roads and streets. However, this effort is even more important when low safety design factors are used in order to cut costs. The soils information available for low-volume facilities varies widely. Some agencies obtain complete soil surveys and laboratory tests to classify soils in the upper 3 ft (0.9 m) of an existing roadway. Others merely assume some standard soil condition without benefit of soil studies. It is usually desirable for each project to use field exploration supplemented with laboratory testing or aerial photographs to determine the range of soil types (usually AASHTO classification) and their probable behavior. Some states have agricultural or engineering soil maps or soil data reports that are helpful in evaluating the soil characteristics. Performance records on other pavements in the area are also helpful in locating bad drainage situations, soft or resilient spots, frost boils, or soils subject to large volume changes. It is assumed that bad spots and unsatisfactory sections of roadway will be corrected.

The final step is to determine the supporting value (CBR or k) to be used in design of the pavement thickness. This may be done by testing the roadway soils, by using test data from other soils in the area, or by using known values for the particular soil classifications on the road.

Exposure Elements

The availability of data on temperature, number of freeze-thaw cycles, frost depth, and precipitation varies from locality to locality. Some state highway agencies have developed quite complete information and others have little other than what is available from area weather stations. Some agencies have helpful data based solely on past experience.

The traffic use and the anticipated weather conditions can be evaluated to estimate how frequently deicing chemicals and abrasives should be applied to the pavement. Adequately air-entrained concrete has good resistance to deicing chemicals.

Some of the design considerations that are dependent upon good exposure data are subgrade treatment, amount of crown, the mixture and its thickness, and the need for protective coatings.

Aggregates

The quality and location of aggregates suitable for the project are identified during the planning stage. Requirements for grading and processing should be established for the most likely sources. Test data usually are available from state highway materials departments or engineering testing laboratories. If not, sampling and testing is necessary.

Equipment and Construction Experience

Because lower prices are likely to result when several contractors are interested in a project, design of the pavement should be considered in light of the construction equipment and experience available in the area. If the pavement cost is to be kept to a minimum, the designer must be aware of the types of equipment used by area contractors and the production capacity that can be expected. Equipment limitations and operational procedures are also evaluated as part of the design decision when specifying concrete pavement for low-volume roads. Much of the information on contractors' equipment is known to county and city officials. If not, the state highway agency, equipment manufacturers, trade associations, or contractors' groups can provide data.

GEOMETRIC DESIGN

Changes in the geometric section from project to project and on individual projects increase construction costs and should be avoided. Additional costs are particularly significant for low-volume roads and streets. There is a recognized need for standardization of the pavement section in order that available equipment and construction techniques can be used on these projects (*9*).

Horizontal and Vertical Alignment

Requirements for paving mailbox turnouts, driveways, and intersections with concrete on rural roads add much cost and slow production. Most designers recognize this and make other provisions for this work.

Expressed concern exists regarding some tendency to overdesign horizontal and vertical alignment for concrete paving on low-volume roads. The improvement should be thought of more as a resurfacing procedure fitted into the existing road. Changes in horizontal and vertical alignment will usually increase a project's cost significantly and are not usually undertaken on low-volume facilities. However, poor alignment may contribute to traffic hazards at the higher speeds that are likely on improved surfaces; hence, a balance must be met.

Most county roads that are to be paved with concrete have base or surfacing material in place and the new grade line usually is adjusted to make use of this material. One Iowa county has a computer program for setting the new grade line to make maximum use of the material. However, officials of other counties have attempted to use in-place materials and have concluded that it was not worth the effort. Other factors that also may affect the selection of the grade line include local high water table, probable snowdrifting, and excavation costs. It appears that whenever practicable, the grade line should be fitted to use existing materials.

City streets have little flexibility in grade lines and usually no attempt is made to adjust the grade to use existing materials, although it might be desirable to do so in some situations.

Pavement and Shoulder Widths

Pavement and shoulder widths on rural roads are influenced primarily by traffic volume and design speed. PCC pavements built on low-volume roads during the past 20 years have been from 20 to 24 ft (6.1 to 7.3 m) in width. Pavements for roads carrying up to 750 ADT generally have been 22 ft (6.7 m) wide. Over 750 ADT, they have been 24 ft. Shoulders vary from 2 to 9 ft (0.6 to 2.7 m), being mostly 4 ft (1.2 m) wide for lower volumes and 6 ft (1.8 m) wide for the upper range.

Widths of moving lanes and parking lanes on city streets vary according to use classification, traffic volume, design speed, and parking practices. Most moving lanes are 10 to 12 ft (3.0 to 3.7 m) wide; however, 9-ft (2.7 m) moving lanes have been suggested for residential streets with speeds under 25 mph (500 ADT with parking and 1,000 ADT without parking). The Federal Housing Administration has permitted 8-ft (2.4 m) moving lanes and 8-ft parking lanes on one-way loop, residential streets. Parking lanes vary from 6 to 10 ft (1.8 to 3.0 m), but most are 8 ft wide. Low-volume streets in residential areas vary in width from 25 to 36 ft (7.6 to 11.0 m), measured from back to back of curb.

CONTROL OF OTHER DESIGN FEATURES

The performance of the pavement is affected by a number of factors that cannot be logically controlled in mixture or thickness design. It is more economical to control these factors in some way to minimize their harmful effects.

Drainage

Pavement Crown

Pavement crowns are provided to drain water from the surface. Steep crowns drain the water but can also cause driver control problems. When curved (circular or parabolic) crowns are used, flat spots often occur that do not drain and, thus, hold salt solutions. Curved crowns are also more difficult and costly to construct. The straight slope or A-shape crown is much preferred for rural roads, although a few agencies do use curved crowns. City streets are more evenly divided between the two shapes.

Crown slopes mostly vary from ⅛ to ¼ in. per foot (10 to 20 mm/m) with a total crown of 2 in. (50 mm) for a 24-ft (7.3 m) pavement being a most common value for low-volume roads. The crown slope for a 36-ft (11 m) city street ranges from 4 to 6 in. (100 to 150 mm).

In certain cases where deicing chemicals might penetrate the concrete, pavement crown height may need to be increased to attain good drainage, particularly if burlap drags that produce longitudinal ridges are used to texture the pavement. A broom or a groove roller having transverse ridges and valleys provides good surface drainage.

Shoulders

Low-volume rural roads, for the most part, have grass shoulders; however, where vehicles make more use of shoulders, some granular materials are used. Slopes of ½ in. per foot (40 mm/m) are common within a ¼- to 1-in. per foot (20 to 80 mm/m) range. City streets without curb and gutter use both sod and granular materials. The use of a slope of ¼ in. per foot (20 mm/m) is common practice for bituminous-treated shoulders.

Ditch Depth and Grade

On low-volume rural roads, ditch depths vary according to the water table and the soil type. Ditch depths below the pavement edge range from 3 to 5 ft (0.9 to 1.5 m) with 4 ft (1.2 m) being common. The minimum ditch grade varies from a flat grade to a 2-percent value with 0.5 percent being common. City streets without gutter may have ditches up to 18 in. (460 mm) deep with a minimum grade of about 0.25 percent. Deeper ditches present a safety hazard and a satisfactory compromise between good drainage and acceptable safety is required.

Curb and Gutter Sections

Low-volume city streets usually have fewer drainage problems and a neater and more attractive appearance when curb and gutter are used with catch basins and storm sewers, although this configuration raises the cost. The designs vary from integral curb on top of the pavement edge to separate curb and gutter sections from 12 to 30 in. (300 to 760 mm) wide with most being 24 in. (610 mm). In residential areas, 3- to 4-in. (75 to 100 mm) rolled curbs to avoid driveway cuts are used, while 6- to 8-in. (150 mm to 200 mm) straight curbs are used for more heavily traveled streets having higher speed limits. Integral curbs present no problem with slip-forming equipment and they strengthen the slab edges.

Subsurface Drainage

Underground drains (pipe with graded granular backfill) are used to intercept springs, lower the water table, drain wet spots where flow on top of impervious layers comes out into the subgrade, or to prevent water from reaching frost boil areas. Thin low-cost pavements do not have much capability to bridge unstable areas. Even a few bad spots in a long stretch of good pavement are not acceptable to the users.

Subgrade Stability

The success or failure of PCC pavements for low-volume facilities is extremely dependent on the stability of the supporting subgrade. It is not practical to correct failures once paving has been completed. Therefore, a dedicated effort to locate potential problem areas is required of the designer.

Base

It is agreed that base is not required under concrete pavement for low-volume roads and streets except where the percentage of heavy vehicles is unusually high. Pumping is not a problem unless there are large numbers of heavy wheel loads and the pavement foundation is wet.

Frost Boils

Wherever frost penetrates a subgrade having frost-susceptible soils and a supply of water, pavements of any type can be seriously damaged. Therefore, these conditions require some treatment to prevent frost boils. Some Iowa counties have been successful in placing a 1½-in. (38 mm) sheet of polystyrene on the subgrade over potential or existing boil areas as an insulation to prevent freezing. However, this practice is not generally recommended because some states have had serious problems. Because the pavement is not heated by the soil below, unexpected icy spots develop on the surface under certain weather conditions. It is common practice to remove the frost-susceptible soil to the average depth of frost and replace it with better soil or with granular materials. Some prefer to stabilize the problem soil with lime or cement to a depth sufficient to eliminate the frost action. Selective grading can be used to minimize the amount of frost-susceptible soil that is directly beneath the pavement. Frost action also can be prevented by cutting off the water supply to an area by installation of underground drains.

Each existing or potential frost boil is somehow unique and tests engineering knowledge and experience to find the most economical and satisfactory solution. But the costs of this effort are small when compared with that of repairing or replacing the pavement.

Additional information on pavement design in frost areas can be found in Synthesis 26 (*10*).

Uniformity of Subgrade Support

Most pavements are designed for a one-subgrade supporting value. It is not always economical to design for the lowest value that may be anticipated. Procedures to upgrade problem areas and provide uniform support will assure better pavement performance and permit more economical pavement designs as the safety design factors can be less. Soils often vary widely in their characteristics along the grade, sometimes changing sharply in their supporting value. There are also variations in the moisture content along the grade that affect the supporting value. Today's earth-moving and soil-processing equipment can treat the subgrades to provide uniformity and higher support values at reasonable prices. Often it is practical to improve the subgrade if savings can be realized in the design of pavement with a strong likelihood of good performance.

The AASHTO Interim Guide (*11*) suggests that certain steps that might be applicable to low-volume roads and streets be considered during design:

- Include an appropriate density requirement for roadbed soils.
- Provide special treatment for expansive or resilient soils.
- Treat frost-susceptible soils in frost areas.
- Replace or cover highly organic soils.
- Blend or treat unusually variable soil types.
- Check both surface and subsurface drainage to eliminate water problems.
- Blend or treat cohesionless soils and wet plastic clays to provide a working roadbed for construction.

These steps are followed by several agencies that have been building concrete pavements for low-volume roads and streets. Examples of specific procedures in use are:

- Scarifying the top 6 in. (150 mm) (in some cases 12 to 15 in.—300 to 380 mm) of the subgrade for the full road width, incorporating the granular materials on the road and recompacting uniformly near optimum moisture content to 95 percent of standard density.
- Selective placement of soils in upper 3 ft (0.9 m) of subgrade during grading operations.
- Blending, sometimes as much as 1 ft (0.3 m) deep, of variable soils along the grade, particularly those with a high plasticity index, to eliminate sudden changes in soil type and thus improve uniformity of support. In some locations, blending may involve removal and replacement of material to greater depths.
- Use of existing granular materials or lime stabilization to improve support in bad locations and to minimize the effects of high-volume-change soils.
- When practical, roads are graded one or two years prior to paving to obtain compaction by traffic and to correct any problem areas that become evident in the subgrade.

Joints for Stress and Crack Control

Longitudinal Joints

To reduce warping stresses and control longitudinal cracking of concrete slabs, longitudinal joints are placed such that they divide the slab into widths of usually 12 to 12½ ft (3.7 to 3.8 m) (some cities use 14 to 15 ft—4.3 to 4.6 mm). Joints may be sawed (d/4 or 2 in.—50 mm—minimum) or formed by inserting plastic or removable metal strips or metal keyed joints ahead of the paver. To prevent the crack over a joint from opening, deformed tie bars (No. 4 or No. 5, 30 to 36 in.—760 to 910 mm—in length) are placed across the joint, spaced at 18- to 48-in. (460 to 1,220 mm) centers with 30 in. (760 mm) being the most common. However, 48-in. spacing has been used on a large mileage of low-volume pavements.

Expansion Joints

Many years of experience have shown that the omission of expansion joints saves money and gives better performance by reducing exposure to tensile stresses, which are far more damaging to concrete than compressive stresses. It is generally agreed that expansion joints in plain concrete slabs should not be used except in unsymmetrical intersections and at fixed structures such as utilities, intersecting pavements, bridges, and railroad tracks.

The joints used at these locations range from ½- to 1-in.

(25 to 50 mm) premolded bituminous fiber joints to 4-in. (100 mm) joints using foam plastic or bituminous filler. Some use dowels at 12- or 30-in. (300 or 760 mm) centers, but many do not use dowel bars.

Contraction Joints

Joints to control the inevitable cracking of concrete when it cools and contracts are almost always used for low-volume roads and streets. Most are sawed (d/4 or 2 in.—50 mm—minimum) at spacings of 12 or 40 ft (3.7 to 12 m) (mostly at 40 ft for rural roads and 20 ft—6 m—for city streets). Sometimes fiber, plastic, or removable metal strip inserts are used. Some agencies use random spacing of the joints and skew them (4 ft—1.2 m—for a 24-ft—7.3 m—width is common) to improve the riding quality.

Load transfer usually depends on aggregate interlock. In practice, dowels generally are not used on low-volume facilities unless subjected to heavy truck traffic.

Construction Joints

Requirements for construction joints vary widely. A few place no restrictions on what the contractor may choose to do. Others require keyed joints with dowel bars at 12-in. (300 mm) centers or the thickening of the slab at the joint by 2 in. (50 mm). Construction joints are not usually permitted closer than 10 ft (3 m) to another joint. Because there is no aggregate interlock across a construction joint, some type of load transfer is needed. This requirement should be kept simple and standard to minimize cost.

Joint and Crack Sealants

Hot-poured rubber asphalt is the most frequently used material. Other sealants are available and are discussed in greater detail in Synthesis 19 (*12*).

Protective Surface Coating

Surface coatings have been developed to protect concrete from the effects of deicing chemicals or extreme freeze-thaw conditions on the surface of the slab. Although linseed oil and a solvent (mineral spirits or kerosene) in equal proportions are used, their efficacy is controversial. In some cases long-range durability studies indicate that the protective coating may actually accelerate the rate of deterioration (*13*). If used, the coating should not influence the curing method and should be placed only after the concrete is dry. Care must be taken in its application to avoid the creation of dangerous slippery conditions. Such treatments are not needed on properly air-entrained and properly cured concrete.

Most agencies do not use any protective surface coating on low-volume road and street concrete pavements. Some use it only on pavements poured late in the fall that do not gain full strength before cold weather. Only a few use it as a regular practice. Because low-volume facilities usually have a minimum of deicing chemical applications, it is questionable whether protective coatings are worth the cost.

Reinforcing Steel

There is general agreement that reinforcing steel is not needed in concrete pavements for low-volume roads and streets. It would make the cost of such a pavement prohibitive for its intended purpose. However, selective use of wire fabric or reinforcing bars can be very effective when used in bridge-approach slabs, in railroad approaches, over sections of unsatisfactory subgrade, and in irregularly shaped slabs having large cutouts. In general, the use of a jointing pattern that reduces slab lengths to approximately 15 to 20 ft (4.5 to 6.1 m) makes the use of steel unnecessary.

MIXTURE PROPORTIONS

Quality

The objective in selecting mixture proportions is to obtain the desired quality by the most economical combination of materials and the use of proper construction procedures. This could require the use of a higher proportion of cement to permit the use of low-quality local aggregates. On the other hand, less cement and a low water-cement ratio may be used even though the lower slump may increase the handling costs. Although materials laboratories of state highway departments, engineering testing laboratories, the American Concrete Institute (*14*), and the Portland Cement Association (*15*) can provide useful information regarding concrete mixtures, there is less information available concerning the quality of concrete that will give satisfactory performance for low-volume roads and streets where low cost is a major consideration. The engineer should have some flexibility to proportion a mixture that will produce concrete of the desired quality at the lowest cost for each project. Local agencies have determined what strength and durability values are necessary to give satisfactory performance for their low-volume roads and streets.

Flexural Strength

Requirements for flexural strength vary from 450 psi (3,100 kPa) in 7 days to 750 psi (5,200 kPa) in 28 days. In making comparisons it should be noted that methods of testing affect the values. Concrete placed late in the fall may need higher early strength to offset its slow gain in strength during the winter months.

Durability

Direct durability tests are not usually performed on concrete produced for low-volume projects. In general, durability varies with compressive strength and the amount of entrained air. Air-entrained concrete with a 28-day strength of 3,500 to 4,000 psi (24 to 28 MPa) can be expected to have satisfactory durability if deicing chemical use is relatively low and if aggregates, cement, and water have the characteristics to produce durable concrete. Good batch plant and field control produce uniform quality concrete, which, in turn, does much to ensure durability. Entrained air from 4 to 7 percent in the concrete does much to enhance durability while also increasing the yield, increasing workability, and reducing the bleeding tendency of the concrete.

Aggregates

Local aggregates available near the job can cut costs. Therefore, all aggregates that can produce concrete of the desired quality should be considered. Indications are that a single coarse aggregate of 1 to 1½ in. (25 to 38 mm) maximum can cut production and handling costs and give more uniform concrete and better strength. A reduction in the maximum size also may improve resistance of the concrete to frost action. With maximum size more than 1½ in., special equipment and care in handling are essential to permit the use of a single coarse aggregate without segregation, thus adding to costs.

A single coarse aggregate of 1½ in. (38 mm) maximum size is most commonly used. The potential of coarse aggregates for D-cracking should be investigated, especially in the Midwest.

Gradings of aggregates vary considerably, with the aggregate passing the No. 4 sieve ranging from 30 to 60 percent, but mostly from 35 to 50 percent.

Cement Type and Content

Type I cement, used with an air-entraining admixture, or Type I A air-entraining cement are predominantly used for low-volume roads and streets although other types are used. Cement content varies widely depending on the desired balance of strength and durability and the cost of the concrete. Severe freeze-thaw areas, locations where large amounts of deicing chemicals are used, and routes having high traffic volumes on poor subgrades will require higher cement factors than areas having milder temperatures and lower traffic volumes on good subgrades. Engineering analysis is required to balance the necessary quality of concrete against its cost because cement content is a major item in both quality and cost. Cement contents of pavements placed on low-volume roads and streets have varied from 470 to 570 lb per cubic yard (280 to 340 kg/m^3) with a good portion of them between 490 and 515 lb per cubic yard (290 and 310 kg/m^3). Kankakee County (Illinois) built an experimental concrete project in 1971 using 470 lb of cement per cubic yard (280 kg/m^3) with a very low water-cement ratio. A modulus of rupture (3-point loading) of 590 psi (4,100 kPa) was achieved in 7 days and a compressive strength of over 4,600 psi (32 MPa) in 28 days. The quality of the concrete is influenced by the properties and grading of the aggregate, water content, construction procedures, as well as cement content. All these factors must be considered together in proportioning a mixture; cement content cannot be considered alone.

Water Content

Low water content improves both the strength and durability of the concrete. In addition, low water-cement ratios are helpful in maintaining the skid resistance qualities of pavement surfaces. Water-cement ratios on low-volume road and street projects are reported to vary from 0.39 (4½ gal per bag—0.4 l/kg of cement) to 0.60 (6¾ gal per bag—0.6 l/kg), but most are in the range between 0.44 (5 gal per bag—0.44 l/kg) and 0.53 (6 gal per bag—0.53 l/kg). Slumps vary from 1 to 4 in. (25 to 100 mm), but are mostly 3 in. (75 mm) or less. High-slump concrete cannot be used with slip-form pavers because of the sloughing of the pavement edges.

Admixtures

Water reducers, retarders, and accelerators have been used in addition to air-entraining admixtures. However, the economies of these admixtures should be investigated.

THICKNESS DESIGN

To build concrete pavements that perform well over their design life with properly balanced construction and maintenance costs, it is essential to:

- Provide reasonably uniform support.
- Prevent pumping (if there are repeated heavy wheel loads).
- Use a joint design that controls warping stresses.
- Design the thickness to keep load stresses within safe limits.

Pavement Cross Section

Nearly unanimous agreement exists that uniform thickness of pavement, and integral curbs, is the preferred form for ease and economy of construction. Thickened edges on the pavement bottom do not necessarily give better performance or lower maintenance requirements. Uniformly thick pavements generally have been constructed for low-volume roads and city streets in recent years.

Design Methods

Design procedures are based on four sources of information: theoretical analysis, laboratory research, test roads, and pavement serviceability. Other considerations are anticipated traffic, subgrade strength, concrete properties, and design life for the project. Because flexural stress is critical in concrete pavements, it is used in thickness design. Concrete pavements will take an unlimited number of stress repetitions without loss of load carrying capacity if the flexural stress ratio (ratio of the actual flexural stress produced by a wheel load to the modulus of rupture of the concrete) is below 0.55. At higher stress ratios the fatigue principle applies, and only a limited number of the heavier loads can be carried before the concrete fails. This is why the reliability of the projections of axle loads is so important. Any substantial increases in the actual number and weights of heavy axle loads on the road over those predicted and used in the thickness design will reduce serviceability, increase maintenance costs, and shorten the life of the pavement. As the number and weights of loads increase, the thickness of the slab and strength of the concrete become more critical in terms of pavement serviceability and life. This emphasizes the importance of good control of slab thickness during construction and uniformity of concrete quality. It also explains why relatively thin concrete pavements can give excellent service over a long life when they are exposed to only small numbers of vehicles having heavy axle loads.

Reliable data on the number and weights of future traffic loads, the subgrade strength, and properties of the concrete must be assembled and a design life selected. The next step is to determine the pavement thickness after considering fatigue life and the projected vehicle loads during the pavement design life. The PCA method (*16, 17*) arrives at a trial pavement thickness by grouping the axle loads in 2,000-lb (900 kg) increments and summing the percentage of fatigue life consumed by the numbers of vehicles in each increment. The AASHTO method (*11*) converts all axle loads to equivalent 18-kip (8,200-kg) single-axle loads and then determines the thickness necessary to prevent the serviceability index from dropping below a selected level (see Appendix A for examples). States have modified these design methods and developed other approaches to thickness design. The basic factors are the same, but the methods of putting them together vary.

Although the design engineer has little influence on the predicted traffic volume and weights, he may adjust the other factors of design life (subgrade support, concrete strength and pavement thickness) to find an optimum balance for cost versus service. Several trial combinations are useful in making the best choices for each job.

Thickness in Use

Experience accumulated to date indicates that excellent service can be expected from properly designed and constructed low-volume rural roads having concrete pavements ranging from 6 to 8 in. (150 to 200 mm) thick and low-volume city streets having concrete pavements 5 to 7 in. (125 to 175 mm) thick. At present, 6 in. is by far the most common thickness for both.

CHAPTER FOUR

CONSTRUCTING THE PAVEMENT

HANDLING LOCAL TRAFFIC DURING CONSTRUCTION

Careful planning of how best to handle local traffic during construction should be done long before starting the project in order to minimize traffic interference and maintain good public relations with local residents. Newspaper publicity and personal contacts with residents are desirable to explain the benefits of the project and the plans for local traffic movement. Residents can point out their traffic needs during the construction period and may offer helpful suggestions that can be incorporated in the plan.

Any special problems of getting products to market or of receiving shipments of materials and supplies can be minimized by working out time scheduling arrangements with the parties concerned. A well-publicized plan for the use of detour routes and the scheduling of open intersections across the project can reduce traffic delays and complaints. Provisions for temporary surfacing or detours should be included in the plans. High-early-strength concrete can be used at intersections to allow opening to traffic in 24 hours.

Again, low-volume roads and streets are primarily land access facilities, and a well-developed and properly executed plan of handling this traffic during construction is imperative.

PREPARING THE SUBGRADE

Although much attention is given to subgrade stability and uniformity in planning and design, final decisions on the construction effort and expense often must be made during construction.

Blending Varied Soils

Soils of different types can be mixed by scarifying and blading with the motor grader (Figs. 10 and 11). If greater depth or more longitudinal movement of the soils is desired, scrapers can be used. If more mixing is wanted, tillers and pulverizers are used. Removal and replacement is usually done with scrapers or loaders and trucks when haul distances are long.

Incorporating Existing Road Materials

Granular materials on the road can be scarified, shaped to grade, and recompacted in place or they can be bladed to one side until all required subgrade treatment is completed and then spread over the surface and compacted. One Iowa county tries to retain the existing road materials for use in the top 3 in. (75 mm) or more of the subgrade so that the fine-grader makes its cut in this material.

Compacting Subgrade

Although partial compaction is done during the grading operations, more uniform subgrade support is obtained by scarifying to a depth of 6 in. (150 mm) or more (even 12 to 15 in.—300 to 380 mm) for the full width of the grade and recompacting to specified density before fine-

Figure 10. Scarifying and blending varied subgrade soils.

Figure 11. Subgrade shaping.

grading. Sheepsfoot, vibratory, rubber-tired, and steel-wheel rollers are used depending on the soil types and conditions (Fig. 12).

Fine-Grading

Rough-grading to within 3 in. (75 mm) of final grade is common. On rural roads, the electronically controlled fine-grader gives excellent results. The subgrade should be compacted to the required density before the final pass of the fine-grader. With the use of a conveyor to take the concrete from the batch trucks and move it over the fine-grader to placement, the fine-grader can be run immediately in front of the slip-form paver giving a fresh, clean grade that requires no wetting or paper (Fig. 13). On city streets grading can be accomplished by motor graders, subgrade planers, or by hand.

Moistening of Subgrade

When the fine-grading is not done immediately ahead of the concrete placement, the grade can be sprinkled or be laid over with waterproof paper or other type of vapor barrier so that the concete is not placed on a dry grade that would remove too much water from the concrete.

MATERIALS HANDLING

Aggregates

Careful handling of aggregates is specified to avoid their segregation and prevent their mixing with dirt or other foreign materials regardless of whether using trucks, conveyors, endloaders, or clamshells.

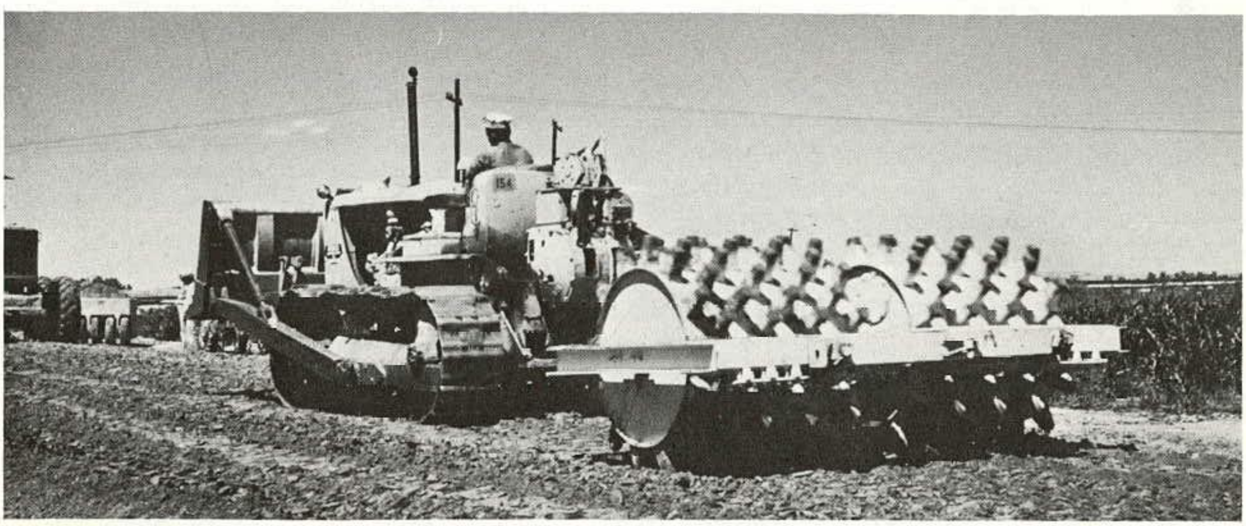

Figure 12. Subgrade compaction.

Cement

Bulk cement is hauled in tanker trucks and is transferred to bins by means of air or by gravity flow. Adequate protection from moisture must be provided during hauling and storage.

Batching and Mixing

Bin storage and automatic batching plants with large-capacity central mix units are used for low-volume rural road construction and large city street projects. Mixing time can vary from 40 to 75 s, which is often based on performance testing, with 55 to 60 s being common (*18*). Many smaller city projects use automatic batching plants and ready-mix trucks.

Hauling

End- or side-dump trucks (30-minute time limit) or agitator trucks (90-minute time limit) haul mixed concrete from the central mix plant. Ready-mix trucks also transport concrete. At the job site, the trucks approach on either the grade or the shoulders, the latter only if space is available and soil conditions permit. The highway agency should ensure that there are adequate side and overhead clearances for dump trucks and paving equipment. Examples of possible obstructions are signs, signals, lights, wires, and trees.

PLACING, VIBRATING, AND FINISHING

Forms or Slip-Form Paver

The use of slip-form pavers is most common for low-volume rural road projects, whereas forms are more commonly used on city street projects (Figs. 14 and 15).

Placing, Spreading, Vibrating, and Strike-Off

The haul trucks can dump concrete directly on the grade or into hoppers that convey it either from the side or over the fine-grader into place. The use of hoppers and conveyor belts to transport concrete over the automated fine-grader to be deposited in front of the paver has proven to be efficient and satisfactory.

The slip-form paver spreads, vibrates, and strikes off the concrete. Power spreaders, vibratory or tamping-type finishing machines, or hand spreading and small vibratory screeds are also used depending on the size of the job and the equipment that is available. Adequate vibration is essential to ensure uniform density of the concrete (Fig. 16).

Surface Finish

Concrete finishing for low-volume roads and streets generally follows standard practices (*19*). There are different views about the final surface texture. Some research studies have shown that transverse rather than longitudinal texturing is more effective in maintaining an adequate level of skid resistance over a range of speeds. Transverse texturing also is recommended on the straightaway to remove water and give better skid resistance. Longitudinal texturing is recommended on superelevated curves for better directional guidance.

The burlap or artificial turf drag has been used for longitudinal texturing (Fig. 17), but some states are now requiring transverse texturing either by brooming, grooving rollers, or wire combs.

Texturing properly done at the right time to give distinct ridges and valleys should provide good skid resistance on low-volume roads and streets for many years.

Joint Installation and Sealing

Longitudinal and contraction joints are mostly sawed and plastic, fiber, or removable metal strip inserts can be used to fill the joints. The time of sawing of joints is critical. Joints should be sawed before uncontrolled cracking occurs, but not so early as to cause excessive spalling at their edges. The proper time varies according to temperature,

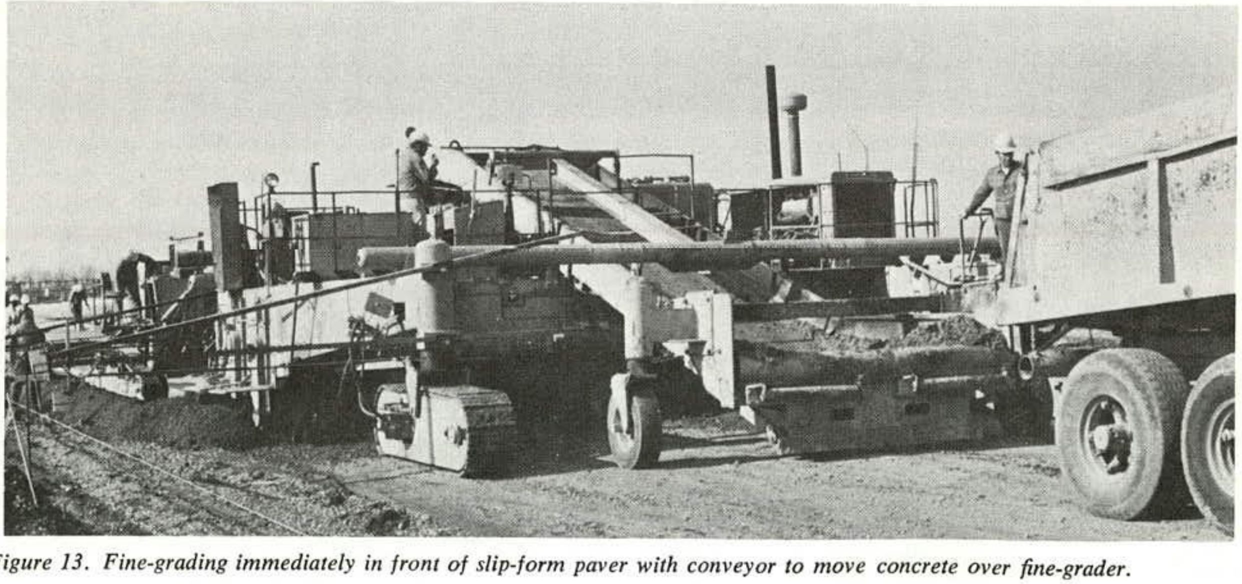

Figure 13. Fine-grading immediately in front of slip-form paver with conveyor to move concrete over fine-grader.

Figure 14. Slip-forming curb and gutter.

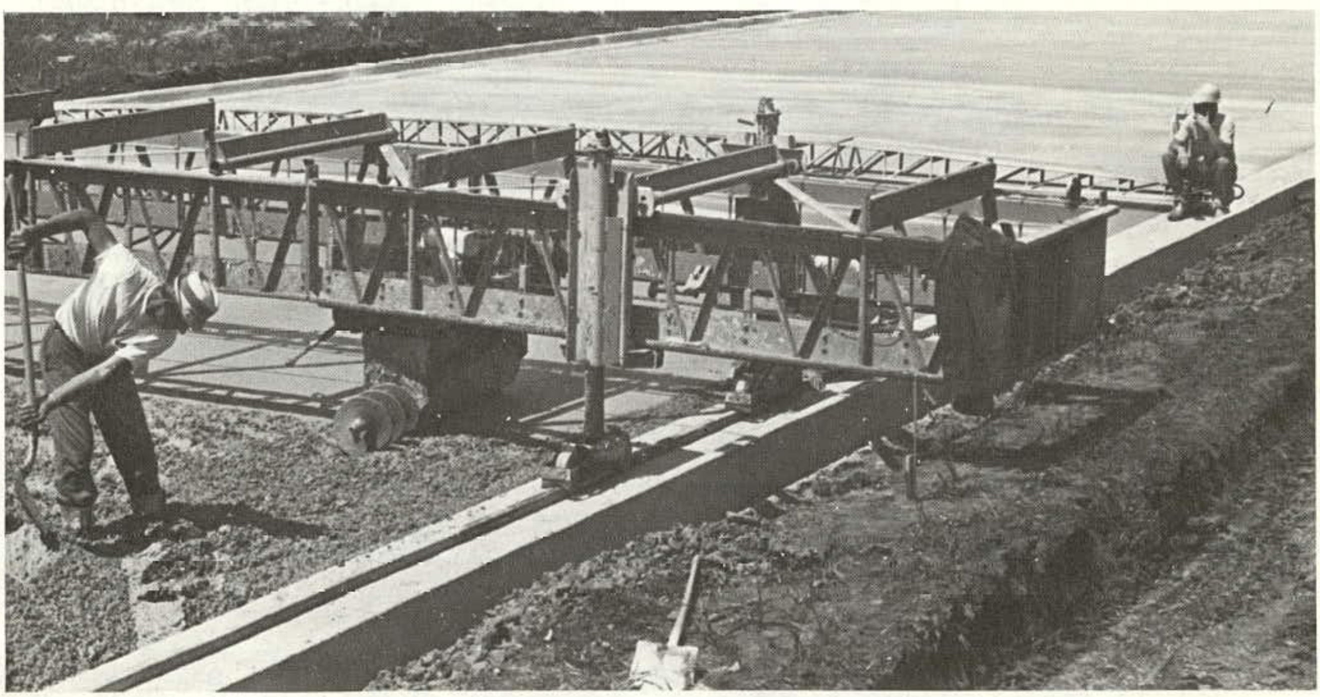

Figure 15. Slip-forming a 48-ft-wide pavement between previously slip-formed curb and gutter.

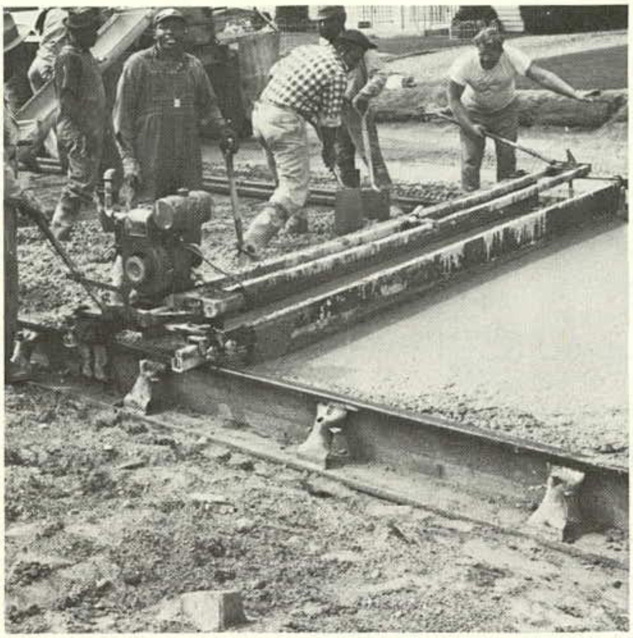

Figure 16. Vibrating hand screed used on a city street project.

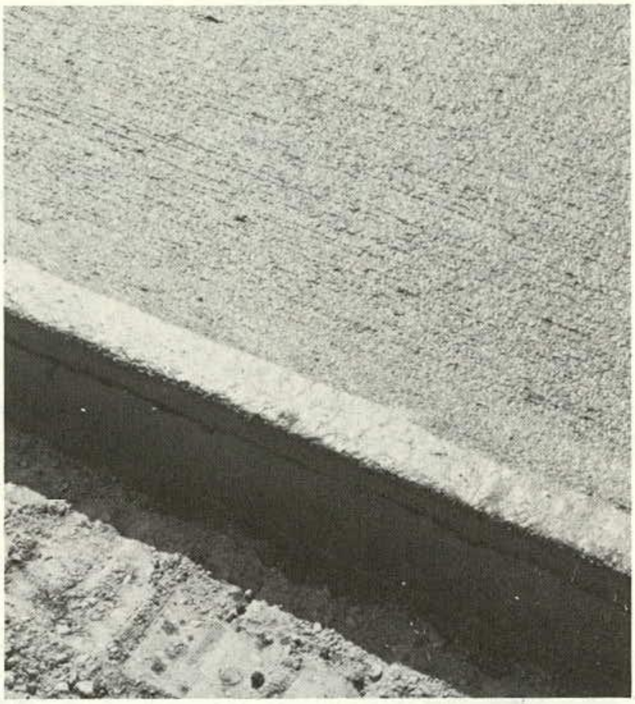

Figure 17. Detail of slip-form placed concrete edge and burlap drag texture.

wind, and humidity as they affect the rate of concrete set. The sawing crews must be trained and scheduled to saw at the appropriate time, which often means that sawing crews must work after placing operations have shut down for the day.

Most agencies seal the joints although some recent contracts have not required joint sealants, and the performance to date of the unsealed joints is not noticeably different from that of the sealed ones. The sealant, usually hot-poured rubber asphalt, is applied by pressure through a nozzle after the joints are thoroughly cleaned and dried (Fig. 18). Sealing is done before any traffic is permitted on the pavement. Fiber or plastic strip inserts are not always sealed.

Surface Tolerances

Surface tolerances on low-volume streets and roads vary from ¼ in. in 10 ft (6 mm in 3 m) for low-speed city streets to ⅛ in. in 10 ft (3 mm in 3 m) for higher-speed rural roads. Several agencies are using roughometer standards as they give a better indication of rideability. Desirable levels for construction are 50 to 60 in. of roughness per mile (790 to 950 mm/km), although low-speed city streets would not require this level of smoothness.

Figure 18. Sealing joints with pressure applicator.

Curing

White-pigmented liquid membrane applied by machine through pressure nozzles (two passes are required by some agencies) is the most commonly used curing agent on low-volume road and street projects (Figs. 19 and 20). However, burlap, straw, watertight paper, or plastic sheets such as polyethylene are sometimes used.

Curing periods range from 3 to 14 days before projects can be opened to traffic, 14 days being the most common. Flexural strengths of 550 psi (3,800 kPa) are specified, although a few require 650 psi (4,500 kPa).

Quality Control

Performance studies show that the type and condition of equipment and the construction techniques are both significant in quality control to ensure good pavement per-

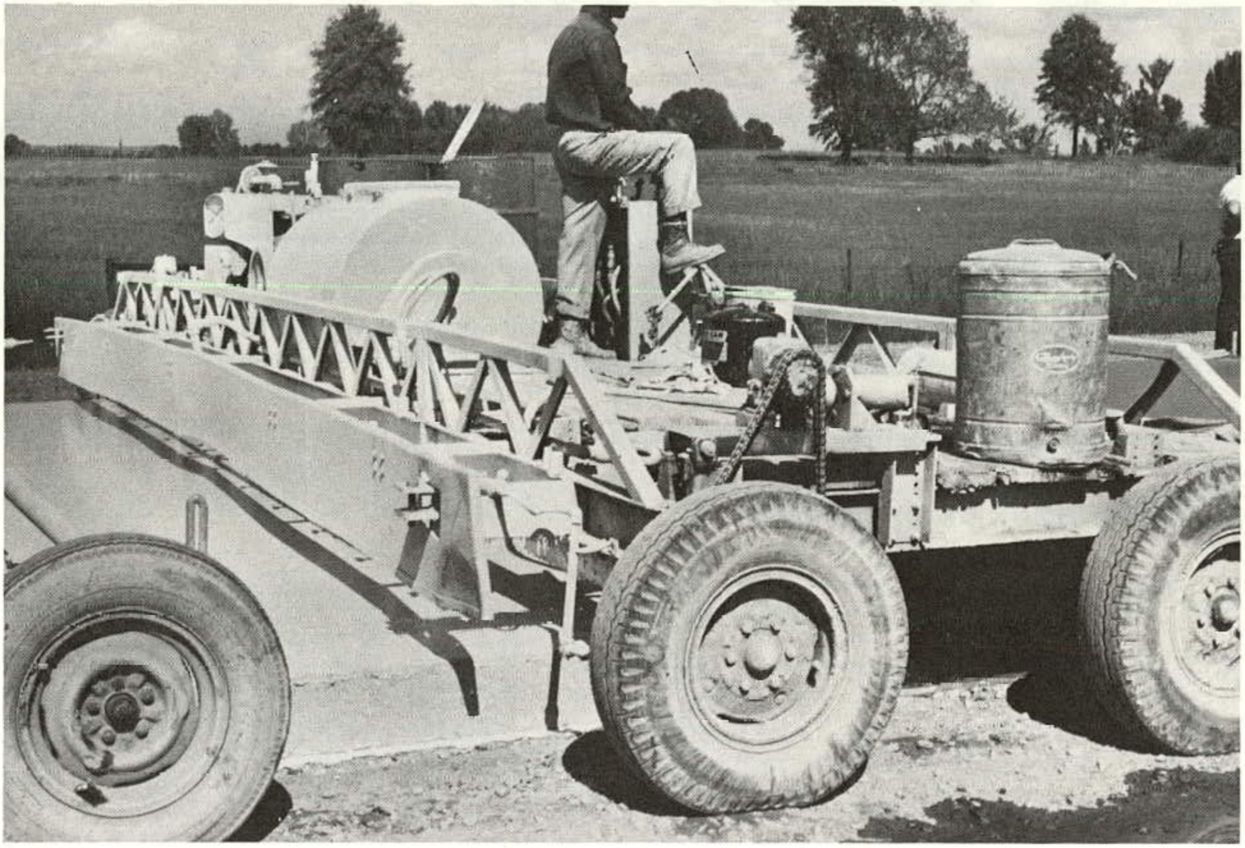

Figure 19. Machine-placed white-pigmented curing compound.

formance. Each of two Iowa contractors who maintained their organization personnel throughout the study period produced pavements with consistently good performance. Other contractors, whose organizations varied, produced pavements that had a noticeable difference in rideability. New York studies indicated that contractor supervision was a major factor in quality control. Uniformity of geometric design, pavement standards, and specifications improves pavement quality, rideability and durability, and also may lower cost. This uniformity enables contractor crews to become more proficient in their work.

Continuous contractor supervision and agency inspection are essential elements in quality control and need to be stressed on construction of low-volume roads and streets.

Thickness of Slab

Electronically controlled fine-grading and concrete finishing equipment, when properly used with frequent checking, will produce a uniform slab thickness. Scratch templates and other inspection techniques are needed on jobs without this equipment.

Before and after cross sections, probes from the surface to the subgrade (sometimes to preset plates) and coring are used to check pavement thickness. Checks on yield give a rough indication of the thickness being obtained. Deductions for thin sections encourage the contractor to provide proper thickness.

Uniformity of Mixture

A uniform mixture is essential for consistent durability and good riding qualities. Good control of materials at the batch plant is necessary for uniform consistency of the concrete. Today's automated plant equipment, when properly checked, regularly inspected and adjusted, produces uniform concrete. Visual inspection and slump tests at frequent intervals are used to check uniformity. Radio communication between batch plant and project site helps control consistency.

Uniformity of Compaction

Concrete must be well compacted without excess voids and honeycomb spots. Checks on the performance and use of the vibrating equipment are necessary.

Riding Quality

Interruptions in the paving operation and lack of uniformity in the mixture are the most common causes of pavement roughness. Slip-form pavers require a steady supply of concrete to assure uniform forward motion, which is essential to produce a smooth riding surface. The paving train speed needs to be adjusted to plant capacity. Two-way radio communication between the batch plant and the paver is helpful to regulate delivery of concrete. When forms are used, stop and start placing and finishing result in a rougher pavement. Some contractors use computers to schedule mixing, hauling, and finishing to minimize delays and to make the most efficient use of the equipment and labor on the job.

Small street projects are not always so efficiently planned. But even here a contractor, to get the most out of his labor and equipment, can do some planning and organizing to minimize stop and start operations.

Grade checking and careful tamping of the form line improve riding quality. Properly used finishing equipment will reduce the amount of hand finishing necessary to get a smooth riding surface. Construction joints are often rough and special finishing care is needed here to avoid bumps.

Air-Entrainment

It is accepted that there is a need for air-entrainment in concrete pavements. However, getting the correct amount is crucial. Overmixing and overworking of the concrete affect the air content. Uniformity in the construction procedures is necessary to maintain uniform air content. Frequent testing with an air meter is the only way to determine if the desired level is being maintained.

The air content range is from 4 to 7 percent, with 6 percent being desired on most low-volume road and street projects.

Curing

Proper curing of the concrete is essential for its strength and durability. Curing protection must begin as soon as the free water has left the surface or the sheen disappears and materials can be applied without marring the surface. The temperature, wind, humidity and rate of concrete set affect the timing. Checks by the inspector are needed to ensure that curing materials are applied at the proper time.

Figure 20. Hand-sprayed white-pigmented curing compound on city street.

CHAPTER FIVE

MAINTAINING THE PAVEMENT

Most of the concrete pavements built in the past 20 years for low-volume roads and streets have required so little maintenance to date that not much experience is available.

SURFACE MAINTENANCE

Protective Coatings

Protective coatings are not commonly used for low-volume roads and streets during construction and even less as a maintenance procedure. Some, such as linseed oil treatments, have been carefully applied where more deicing chemical use was necessary. Sanding may be required to assure adequate skid resistance. Very little protective coating has been laid on city streets.

Joint and Crack Maintenance

Joints and cracks are generally sealed with hot rubber asphalt or similar filler in late fall or winter when the openings are the widest. A few agencies have not done any maintenance sealing to date. Some research is needed to determine whether sealing is justified. Removal of debris from the surface will help to reduce the amount of incompressibles that could enter the joints and cause problems.

Surface Repairs

Few surface repairs have been made on the projects designed and built as low-volume facilities. Shallow repairs are made with hot or cold asphaltic mixes. Cement-sand grout is used by some agencies to bond high-early-strength concrete patches. Others use epoxy resin with cement and sand or commercial products. Deep repairs usually have saw-cut edges and high-early-strength concrete patches. Repairs are most effective when the pavement is warm and dry.

Slippery Surfaces

Low-volume roads and streets normally do not have enough wear to require corrective treatment of slippery conditions. A few reports indicate that studded tires have caused enough wear to pavements to warrant corrective action. Surface treatments are not always satisfactory. Grooving with a diamond saw has been used, but in some cases studded tires wore down grooving effectiveness so quickly that its cost could not be justified.

Deeper texturing of most low-volume facilities during construction may generally reduce the need for subsequent corrective treatment.

DEICING CHEMICALS

Deicing chemicals are used much less on low-volume roads and streets than on primary routes and arterial streets. The rate of use varies with local climatic conditions. Deicing materials are mainly used on curves, hills, and bridge decks, at stop signs, signals, and railroad crossings. Applications are rarely continuous over long stretches of roadway.

Spreaders are usually calibrated to avoid excessive application of materials. Salt, calcium chloride, sand, and cinders may be used separately or jointly. The number of seasonal applications depends on weather, location, and agency policy (*20*). Normally, low-volume facility concrete, because of low-cost design factors, may not have the durability to resist numerous applications of deicing chemicals.

MAINTENANCE OF DRAINAGE

Water trapped along the edge of the pavement is often a cause of pavement deterioration. Ruts are filled, shoulders regraded (½ in. per foot—40 mm/m—or more), and ditches cleaned to keep water away from the pavement. Where rutting becomes too prevalent, aggregate shoulders can be constructed to reduce maintenance. Gutter drainage for city streets is maintained by frequent sweeping.

ENFORCEMENT OF LOAD LIMITS

To keep initial costs down, low-volume facilities are generally designed with a low margin of safety for structural adequacy. Loads on such pavements should be restricted to design limits, which are usually the legal limits for the area. Lower limits are used in some areas during the spring thaw (*10*). Regular publicity regarding the importance of keeping loads within these limits and strict enforcement by the police are essential.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

GENERAL CONCLUSIONS

Concrete pavements constructed during the past 20 years specifically for low-volume rural roads and city streets give ample evidence that such pavements can be designed and built to provide many years of excellent service at low average annual cost. Concrete pavements of this type require planning and design directed specifically to the desired level of service in order to eliminate every avoidable cost and combine the various elements involved to achieve a high-quality pavement.

Any agency responsible for the improvement of low-volume roads or streets might wish to check the following points to determine whether the use of concrete pavement can offer the best long-range solution.

- What level of service does the existing road offer?
- What are the present annual maintenance costs?
- What are the traffic projections for the next 20, 30, or so years?
- What are the soil conditions in the project area?
- What available local materials are suitable for concrete?
- Do local contractors have the necessary equipment and expertise? If not, can they be motivated to acquire such equipment and train personnel in the building of low-cost concrete pavements?
- What are the probable costs of a concrete pavement?
- Are sufficient funds available for a project of reasonable size that would encourage competition and, thus, low prices?
- Considering the probable maintenance costs for such a pavement, how do the average annual costs over its design life compare with those for other pavement types?
- What are the relative levels of service for competitive pavement types?

County highway agencies in Iowa have shown that, with the proper organizational structure and a high level of professional competence, an extensive and effective program of low-volume road improvement using concrete pavements can be conducted. Some cities have had comparable success. Other highway agencies are investigating PCC pavements for low-volume roads and many others may find it advantageous to do so in the future.

SUGGESTIONS FOR REDUCING COSTS AND UPGRADING QUALITY

The following suggestions to reduce costs and upgrade the quality of pavements for low-volume roads and streets were offered by questionnaire respondents and panel members:

- Do not overdesign. Fit the road to the traffic needs.
- Use uniform standards and specifications.
- Base design on performance.
- Award contracts of sufficient size to encourage contractor competition.
- Require adequate field inspection and supervision.
- Plan jobs to use slip-form pavers and other high-production equipment.
- Recognize the need for a workable mixture to keep equipment moving to get a smooth surface.
- Minimize hand finishing requirements.
- Eliminate expansion joints.
- Do not use reinforcing except for tie bars at longitudinal joints.
- Determine whether dowels are necessary on a project-by-project basis.
- Give contractors the option of using locally available materials, including pit run that passes grading and quality requirements.
- Use a single size coarse aggregate.
- Permit contractors the option of using belt conveyors or dumping on the grade, of using sawed or formed joints, and any proven methods of curing.
- Be receptive to suggestions from contractors that could offer additional savings.
- Treat frost boils and frost-susceptible soils prior to paving.
- Avoid geometric designs, such as cul-de-sacs, that require large amounts of hand work.
- Use a standard mountable curb (PCA, 5-in.—125 mm —suggested height) so that special treatment of driveways can be omitted.
- Whenever possible, locate utilities outside the pavement area.
- Complete all utility adjustments before paving is begun.
- Use uniform street and pavement widths and cross section.
- Use integral curbs rather than detached curb and gutter sections.
- Extrude integral curb with the slab.
- Plan intersection traffic so that the contractor can pave continuously in one direction.
- Use high-early-strength concrete at key intersections and crossings so that they soon can be reopened to traffic.

RECOMMENDATIONS

The review of current practice for low-volume PCC pavements emphasizes the complexities of the operation, the numerous factors that affect cost and performance, and the necessity of applying engineering judgment and experience in making decisions. Engineering is a small portion of the cost of a paving project and it is recommended that sufficient engineering effort be available to deal adequately with all phases of the project. A project check list is included as Appendix B.

Standardization of parts, equipment, and methods has contributed to reasonable prices for many convenience products. This is due to higher rates of production and lower unit costs. Highway agencies and contractor organizations that are interested in low-volume roads and streets should coordinate efforts to achieve common standards and specifications for this type of construction that will provide good performance at low cost.

RESEARCH NEEDS

- More specific information is needed on joint requirements (type, spacing, skewing, and load transfer) for low-volume facilities.
- Data concerning traffic patterns, particularly load distribution, on low-volume roads and streets and simple but reliable methods of making traffic predictions for these facilities are needed.
- More cost and benefit data are needed to conduct economic studies of low-volume roads and streets.
- A thorough study should be made to determine whether or not sealing of cracks and joints is effective and whether the cost can be justified.
- If local materials are to be used to best advantage, information is needed on the range in gradation that is economical and satisfactory for use in concrete for low-volume facilities.

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APPENDIX A

THICKNESS DESIGN OF CONCRETE PAVEMENTS FOR LOW-VOLUME ROADS AND CITY STREETS

Empirical data from a number of organizations indicate that properly constructed 5- to 8-in. concrete pavements without reinforcement and without subbase will serve low volumes of traffic adequately for many years with low maintenance costs. The pavement thickness required for any particular project varies with the number and magnitude of heavy wheel loads anticipated for the design life of the pavement, the strength of the concrete, and the uniformity and supporting value of the subgrade.

There are two commonly used methods for thickness design. The PCA method (*16*) is based on theoretical analyses, laboratory data, and field observations. The AASHTO method (*11*) is based primarily on the data from the AASHO Road Test and modified by analytical studies and field experience. Generally, the AASHTO method requires less thickness for lighter weights and lower volumes of traffic than the PCA method. However, the reverse is true for heavier loads and larger volumes of traffic. In Example 1, the PCA method results in a design thickness of 6½ in. Example 2, which uses the same set of conditions within the AASHTO method, results in a design thickness of 6 in. For lower-volume roads or streets with little truck traffic, the AASHTO method results in thicknesses decidedly below the minimum considered desirable for durability as affected by weathering and traffic.

When loadometer data for a project are not available, one can use the probable distribution of axle loads as given in Table A-1 (*21*) and in Ref. (*8*), the latter being the source of data used in Examples 3 and 4.

The examples of thickness design serve to illustrate common procedures used. The designer should use the best information available and his best judgment in developing the following design data for each project:

- Design life.
- Projected volumes of traffic and the axle-load distribution.
- Subgrade supporting values.
- Concrete strength.
- Load safety factor (usually 1.0 for low volumes of truck traffic, PCA method).
- Terminal serviceability level (usually 2.0 for low-volume roads and streets, AASHTO method).

Several trial designs are usually desirable in order to get the best balance of construction cost and the desired level of service with low maintenance costs.

CALCULATION OF CONCRETE PAVEMENT THICKNESS

Example 1

Project:	Example design procedure for low-volume road by PCA method (*16*)
Type:	County rural road with estimated average axle load distribution (Table A-1)
Number of lanes:	2
Design life:	40 years
Current ADT:	700
Projection factor:	1.5
ADTT:	12 percent of ADT
Design ADT:	$700 \times 1.5 = 1{,}050$
Design ADTT:	$1{,}050 \times 0.12 = 126$
Total truck traffic in each lane for design life:	$\frac{126}{2} \times 365 \times 40 = 919{,}800$
Subgrade *k*:	100 (CBR: 3)
No subbase	
Modulus of rupture:	650 psi
Load safety factor (LSF)	1.0
Trial depth:	6½ in.

AXLE LOAD (KIPS)	AXLE LOAD ×1.0 LSF (KIPS)	STRESS (PSI)	STRESS RATIO	REPETITIONS (NO.) ALLOWABLE	REPETITIONS (NO.) EXPECTED	FATIGUE RESISTANCE USED [a] (PERCENT)
			Single Axles			
22	22	380	0.58	57,000	12,730	22
20	20	348	0.54	180,000	22,350	12
18	18	318	0.49			
			Tandem Axles			
40	40	400	0.62	18,000	4,210	23
38	38	382	0.59	42,000	9,650	23
36	36	365	0.56	100,000	17,010	17
34	34	350	0.54	180,000	25,450	14
32	32	334	0.52	300,000	25,860	9
30	30	317	0.49			
					Total:	120

[a] Because total fatigue resistance used should not exceed about 125 percent (for 28-day modulus of rupture), a thickness of 6½ in. is adequate for these conditions.

Example 2

(Same basic data as Example 1)

Project:	Example design procedure for low-volume road by AASHTO method (*11*)
Type:	County rural road with estimated average axle load distribution (Table A-1)
Number of lanes:	2
Design life:	40 years
Current ADT:	700
Projection factor:	1.5
ADTT:	12 percent of ADT
Design ADT:	$700 \times 1.5 = 1{,}050$
Design ADTT:	$1{,}505 \times 0.12 = 126$
Total truck traffic in each lane for design life:	$\frac{126}{2} \times 365 \times 40 = 919{,}800$
Subgrade *k*:	100 (CBR: 3)
No subbase	
Modulus of rupture:	650 psi

Terminal serviceability: 2.0

Traffic equivalence factors based on a trial thickness of 6.0 in.

Working stress: 75% of 650 psi = 490 psi

TABLE A-1

AXLES PER 1000 TRUCKS (ADTT)[a] CALCULATED FROM GENERALIZED PROBABILITY CONSTANTS (PC)

AXLE LOAD (KIPS)	COUNTY RURAL MIN.	AVG.	MAX.
Tandem:			
50			0.27
48			0.27
46			0.44
44			6.85
42			16.25
40		4.58	23.51
38		10.49	30.19
36	4.85	18.49	34.85
34	2.44	27.67	33.26
32	2.41	28.11	27.26
30	2.22	27.37	22.30
28	2.22	23.73	22.30
26	2.22	28.74	22.30
24	3.34	21.89	21.18
22	3.34	14.44	21.18
20	3.34	14.49	21.18
Single:			
26			1.56
24			16.71
22		13.84	33.15
20	4.85	24.30	40.44
18	18.25	56.29	50.41
16	99.95	55.40	57.92
14	99.95	65.32	57.92
12	152.08	207.70	244.14
10	152.08	218.01	244.14

[a] Average daily truck traffic (all 2-axle, 4-tire vehicles and larger).

AXLE LOAD (KIPS)	EXPECTED REPETITION (NO.)	TRAFFIC EQUIVALENCE FACTOR	NO. OF EQUIVALENT 18-KIP SINGLE-AXLE LOADS
Single Axles			
22	12,730	2.32	29,530
20	22,350	1.55	34,640
18	51,740	1.00	51,740
16	50,960	0.61	31,090
14	60,080	0.35	21,030
12	191,040	0.19	36,300
10	200,530	0.09	18,050
8[a]	230,000	0.03	6,900
6[a]	250,000	0.01	2,500
4[a]	265,200	0.002	530
2[a]	13,000,000	0.0002	2,600
Tandem Axles			
40	4,210	3.79	15,960
38	9,650	3.04	29,340
36	17,010	2.42	41,160
34	25,450	1.91	48,610
32	25,860	1.48	38,270
30	25,180	1.13	28,450
28	21,830	0.85	18,560
26	26,440	0.63	16,660
24	20,130	0.45	9,060
22	13,280	0.32	4,250
20	13,330	0.22	2,930
		Total:	488,160

[a] Estimated from traffic data for 2-axle, 4-tire vehicles.

From the AASHO design chart (*11*, p. 26), for 488,160 repetitions, working stress of 490 psi, and $k = 100$, the pavement thickness is 6 in.

Examples 3 and 4

Project:	Examples of design procedure for low-volume city street by PCA Method *(16)*		
Type:	Residential/residential collector with normal axle load distribution and two moving lanes serving 100 lots with single-family detached homes		
Design ADT:	700 *(12)*	No subbase	
Number of axles of truck traffic:	*(3)*	Modulus of rupture:	650 psi
Subgrade k:	100 (CBR: 3)	Load safety factor (LSF):	1.0

Example 3

Design life: 30 years Trial depth: 5½ in.

AXLE LOAD (KIPS)	AXLE LOAD ×1.0 LSF (KIPS)	STRESS (PSI)	STRESS RATIO	REPETITIONS (NO.) ALLOWABLE	REPETITIONS (NO.) EXPECTED	FATIGUE RESISTANCE USED [a] (PERCENT)
Single Axles						
20	20	438	0.67	4,500	820	18
18	18	400	0.62	18,000	1,330	7
16	16	369	0.57	75,000	40	0
14	14	335	0.52	300,000	4,500	2
12	12	300	0.46			
Tandem Axles						
36	36	455	0.70	2,000	1,500	75
32	32	417	0.64	11,000	2,470	22
					Total:	124

[a] 5½ in. is adequate depth for a 30-year life with regard to fatigue resistance.

Example 4

Design life: 40 years Trial depth: 6 in.

AXLE LOAD (KIPS)	AXLE LOAD ×1.0 LSF (KIPS)	STRESS (PSI)	STRESS RATIO	REPETITIONS (NO.) ALLOWABLE	REPETITIONS (NO.) EXPECTED	FATIGUE RESISTANCE USED [a] (PERCENT)
Single Axles						
20	20	385	0.59	42,000	830	2
18	18	353	0.54	180,000	1,370	1
16	16	325	0.50			
Tandem Axles						
36	36	407	0.63	14,000	1,500	11
32	32	370	0.57	75,000	3,190	4
					Total:	18

[a] With only 18 percent of the fatigue resistance used, 6 in. is adequate for a 40-year life and probably for a 50-year life. Since fatigue resistance used should not exceed about 125 percent (for 28-day modulus of rupture), it can be noted that 5½ in. would not be adequate in fatigue resistance for a 40-year life (Example 3).

APPENDIX B

CHECKLIST FOR CONCRETE PAVEMENT PROJECT ON LOW-VOLUME FACILITIES

A. Administrative evaluation and decisions
  1. Economics and financial evaluation
    a. Existing roadway
      (1) Initial cost of surfacing
      (2) Maintenance costs
      (3) Level of service
      (4) Estimated resurfacing or reconstruction interval and costs
      (5) Average annual cost over a 30- to 50-year period (possible design life for concrete pavement)
    b. New concrete pavement
      (1) Estimate of initial construction cost
      (2) Estimated maintenance costs
      (3) Comparative level of service—design life
      (4) Average annual cost for the design life
    c. Availability of funds and possible size of project
  2. Utilities in the pavement area
    a. Type and location of all utilities
    b. Contacts with utility companies on utility plan
    c. Changes and adjustments in utilities (location, surface elevation)
    d. Construction procedures required (trenching, backfilling, compacting, surface finishing)
  3. Construction planning
    a. Availability of equipment types and construction expertise necessary to achieve a high rate of production and good quality
    b. Coordination with other agencies on standardization in order to encourage contractors to acquire appropriate equipment and to develop personnel expertise in its use.
    c. Allowable modification of standards and specifications needed to adapt them to low-volume facilities
    d. Handling of local traffic during construction
      (1) Local contacts to determine needs along the project perimeter
      (2) Detours, temporary surfacing, open intersection schedule
      (3) Advance publicity on traffic plan
  4. Enforcement of load limits
    a. Coordination and planning with policing agency or agencies
    b. Periodic publicity of enforcement plan

B. Traffic
  1. Sources of data (state and urban area transportation studies, traffic maps, field counts, land-use studies and projections)
  2. Projections of future traffic
    a. Current traffic volumes
    b. Possible diversion of traffic from other routes to the improved route
    c. Changes in land use (commercial or industrial development which would increase traffic, particularly trucks)
    d. Projection factors for growth in traffic
    e. Design volume
    f. Axle load distribution (field studies, probability constants)
    g. Design speed (conforming to probable operating speed)
  3. Functional classification

C. Exposure elements in the project area
  1. Precipitation amounts (rain, ice, snow)
  2. Temperature ranges and rate of change
  3. Freeze-thaw cycles
  4. Need for deicing chemicals or abrasives

D. Soils and subgrade
  1. Collection of information (soil maps, aerial photographs, field borings and observations, performance of existing road or roads in the area
  2. Location of special problems (frost boils; highly organic, expansive, or resilient soils; abrupt soil-type changes, soft spots, drainage problems)
  3. Treatment of bad spots (replacement, stabilization, or drainage)
    a. Frost boils or highly frost-susceptible soils
    b. Highly organic soils
    c. Expansive or resilient soils or soft spots
    d. Wet spots
  4. Scarifying, blending, compacting for uniformity of support
  5. Incorporation of existing road materials
  6. Method of final subgrade cut before placing concrete
  7. Evaluation of design value of subgrade support
  8. Most subgrade for concrete placement

E. Drainage
  1. Crown (amount and shape)
  2. Ditches (side slopes, depth, minimum grade, safety)
  3. Curb and gutter
    a. Vertical or rolled-type curb
    b. Integral curb or separate curb and gutter
  4. Catch basins and storm sewer systems for curb sections
  5. Subsurface drainage (springs, frost boils, seepage spots)
  6. Maintaining drainage away from pavement

F. Pavement
  1. Geometrics
    a. Horizontal and vertical alignment (minimum of change to reduce costs consistent with expected

service level and use in-place road materials
   b. Width (determined by traffic volume and speed)
2. Aggregate sources (processing requirements, blending possibilities, specification modifications)
3. Joints
   a. Longitudinal joints (type, location, tie bars)
   b. Expansion joints (type, location, load transfer)
   c. Contraction joints (type, location, load transfer, spacing, and skew)
   d. Construction joints (location, load transfer)
   e. Sealants (type and method of placement)
4. Concrete mixture
   a. Strength and durability standards
   b. Aggregate type, quality, and grading
   c. Cement type and content
   d. Water content
   e. Air content
   f. Admixtures (retarders, water reducers)
   g. Batching and mixing (controls)
   h. Hauling (equipment types, time limits)
   i. Placing and compacting (uniformity)
   j. Finishing (minimize hand finishing)
      (1) Riding quality
      (2) Surface texture (direction)
   k. Curing (method and timing)
   l. Joint sawing (timing)
5. Pavement thickness
   a. Reliability of traffic prediction, uniformity of subgrade support, range of exposure elements, quality control in construction (margin of safety in design)
   b. Determination of thickness (PCA or AASHTO method)
6. Quality control procedures (contractor and inspector coordination)
   a. Thickness of slab (form setting, subgrade finish cut, before and after cross sections, probes with or without preset plates, cores, yield of concrete placed)
   b. Uniformity of mixture (grading and consistency)
   c. Uniformity of compaction (uniform vibration procedures)
   d. Riding quality of pavement (uniformity and continuity of operation)
   e. Air content
   f. Curing procedure

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