NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 38

EVALUATION OF PAVEMENT JOINT AND CRACK SEALING MATERIALS AND PRACTICES

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

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EVALUATION OF PAVEMENT JOINT AND CRACK SEALING MATERIALS AND PRACTICES

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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

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

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

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FOREWORD

By Staff

Highway Research Board

This report contains a current state of the knowledge with respect to the use of highway joint and crack sealing materials and methods and will be of special interest to highway research and materials engineers and technical personnel associated with industrial organizations that supply sealant materials. The researchers have made a thorough literature survey of the subject and prepared an annotated bibliography of about 260 significant items. Needed research on sealants and related factors is recommended as the result of a critical analysis of all information assembled during the study. Because joint and crack sealing is involved in the design, construction, and maintenance of pavements as well as bridges, engineers in these fields may also find information of interest in this report.

In most parts of the country it is considered desirable that joint and crack openings in portland cement and bituminous pavements, at bridge abutments, and along the pavement-shoulder interface should be sealed in some manner to prevent the infiltration of water into the underlying courses and the intrusion of solid material into the openings. Both preformed and sawed joints that are placed to control cracking or allow for expansion of the slabs, and uncontrolled cracks that develop due to other causes, require sealing under most conditions. Present materials and construction practices used in sealing joints and cracks result in highly variable and, in many cases, inadequate performance for environmental, structural, and traffic conditions.

The Rensselaer Polytechnic Institute approach to the problem of evaluating joint and cracking sealing materials and practices was to first conduct a survey of a large number of agencies to collect background information. Responses were received from 60 State highway and turnpike agencies, 8 Canadian Provincial highway departments, 303 cities and counties, 57 universities, and 44 associations and sealant manufacturers. A representative cross section of this group was selected for a more detailed investigation, including personal contacts. A comprehensive literature search was conducted to supplement the information obtained from the survey and all accumulated information was then analyzed to determine the specific areas of needed research.

The recommended research program for determining the best procedures to improve the performance of joint and crack sealing activities is quite broad in scope. It includes studies of pavement movement, skewed joints, construction specifications, testing procedures and the behavior characteristics of the three classes of sealant materials which show the most promise. An education program, involving highway department, contractor, and material supplier personnel, is also recommended to help alleviate the problem of inadequate performance of sealing efforts.

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ACKNOWLEDGMENTS

The work reported herein was conducted at Rensselaer Polytechnic Institute by personnel of the Department of Civil Engineering. John P. Cook, Assistant Professor of Civil Engineering, represented the Institute as principal investigator. He was assisted by Russell M. Lewis, Associate Professor of Civil Engineering, and Dennis J. Fitzgerald and W. Stuart McEwan, Research Assistants.

The assistance and cooperation of many persons and agencies in furnishing information, suggestions and photographs are gratefully acknowledged. Valuable advice and suggestions were received from representatives of State highway departments, turnpike authorities, government agencies, trade associations, and sealant manufacturers. Those organizations that supplied more detailed assistance are listed in Appendix A.

EVALUATION OF PAVEMENT JOINT AND CRACK SEALING MATERIALS AND PRACTICES

SUMMARY

The joints and cracks in pavements are sealed to prevent dirt, stones, and water from entering these openings. Water and incompressible solids in the joint inhibit normal pavement movement and cause extensive pavement damage.

The demands made on the sealant material depend on pavement behavior. The movement of the pavement is a function of joint spacing, joint width, temperature range, moisture content, subbase type, and traffic volume.

The various State highway departments have been quite willing to test new sealant materials, as the new materials were developed. Ten States are currently conducting experiments. Of all the city and county authorities contacted, none indicated any experimentation and almost all indicated some dissatisfaction with current methods.

At present, 68 percent of the States and turnpikes surveyed permit use of hot-poured asphaltic sealants, 10 percent permit use of cold-poured elastomers, and 10 percent permit use of preformed compression seals. Almost all the States indicated an interest in the preformed seals.

Most failures of poured sealants have occurred in the first two winters of service. However, there are successful installations of each of the various sealant types. Many of the sealant failures can be traced to inadequate specification requirements, poor design, spalling concrete, or improper installation.

The current specifications for highway sealants generally contain a bond-extension test as the only performance requirement. More tests are needed to make the specifications effective. An adhesion test, a compression-extension cycle, an incremental extension test, and a stress-relaxation requirement should all be investigated.

Crack sealing is receiving very little engineering attention. Most cracks are simply filled occasionally with a tar or an asphalt.

Research is recommended in the following areas: pavement movement, skewed joints, crack sealing, and each of the basic material types—hot-poured sealants, cold-poured elastomers, and preformed seals.

To supplement the proposed research program and insure its effectiveness, an education program directed toward the improvement of overall sealant performance is suggested to coordinate the efforts of designers, materials engineers, producers, and contractors.

CHAPTER ONE

INTRODUCTION

HISTORY

The proper sealing of construction, contraction, and expansion joints is a problem that has defied practical solution since the beginning of paved roads. As early as 1912, work was being done to develop a better joint which would withstand the rigors brought on by traffic. The earliest concrete highways were made without either longitudinal or transverse joints. The result was an indefinite and irregular crack pattern; consequently, the joint was introduced to control cracking. During this period before the 1920's, the predominant highway effort was to get the country out of the mud. Because it was just the beginning of significant highway construction, there was naturally little sophistication to the art and very little technical data available. Trial and error was the only means of comparing materials and methods for sealing joints. Materials in use at that time were primarily sand, tar paper, cold-tar pitch, asphaltic compounds, and wooden blocks. Knowledge began to expand rather rapidly during the 1920's, so that by 1930 sufficient experimentation had been done and enough experience had been obtained to precipitate discussion of the following factors:

1. The need for expansion joints and their proper spacing when used.
2. The necessity of expansion joints when contraction joints were used.
3. The amount of space necessary at expansion joints (the early concept of joint design).
4. The use of dummy or weakened-plane joints.
5. The use of dowels and closely spaced contraction joints.

By this time the Bureau of Public Roads was sponsoring experimental work and in 1940 and 1941 test pavements were constructed in 5 States in cooperation with the Bureau. A good deal of valuable information was collected in these tests, some of which is evidenced by current practice. This work established the trend away from using expansion joints in nonreinforced pavements. Expansion joints were used only at structures or at other locations where stress relief was particularly necessary. The result was pavements that were more resistant to pumping and faulting because of the maintenance of more effective aggregate interlock at the joints.

Progress was being made and the end of World War II found most communities facing the problems of rehabilitating existing plants and providing for rapid traffic growth. The subsequent emphasis on highway design gave a new impetus to the attempts at solving the sealing problem. The hot-poured sealants, particularly the rubber asphalt compounds, were still the most popular materials for filling joints. However, their rather rigid heating control requirements led to the search for cold-applied mastics. By 1950 several test installations had been made with cold-applied mastics, but none were satisfactory. The most common problem was a bond or adhesive failure. Preformed, precompressed rubber for expansion joints, developed by B. F. Goodrich about 1931, was not unknown at this time. The original method was to place the rubber gasket in the wet concrete, whereas the usual current method is to place the gasket with a wheel device into a formed or sawed joint after the concrete has hardened. Early field applications of the rubber seals encountered difficulty because the material was deformed during placement in the pavement. It was often knocked askew in the placing or finishing operations; hence this material did not have an opportunity to perform adequately.

The 1950's also saw the development of elastomers for use in sealing highway joints. The 2-component polysulfides were the first polymer-type sealants to be used in highway joints. Urethanes and other elastomers followed. Unfortunately, many of these new products were put on the market prematurely, as most contractors were not accustomed to dealing with such exotic materials. Many mistakes were made which even today cloud the performance picture. During this period, many of the more progressive States conducted studies of pavement movement and instituted test installations of sealant materials.

A recent development which looks promising is the presealed joint. This unit consists of 2 stainless steel plates and a precompressed sealant material which may be either extruded Neoprene or an asphalt-saturated foam. The precompressed assembly is vibrated into the wet concrete immediately behind the paving train, thereby forming and sealing the joint.

In past practice joints have been deprived of engineering attention, and rules of thumb have been indiscriminately applied. It is only quite recently that the real seriousness of the joint problem has been fully realized, and consequently the demand for improved materials and practices has risen sharply.

DESCRIPTION OF THE PROBLEM

Openings between adjacent highway slabs are sealed to prevent the intrusion of foreign material, water, and chemical deicing solutions. Sealing techniques are employed for transverse expansion and contraction joints, longitudinal joints, and cracks. In highway pavements on grade, infiltration of water into the joint may result in deterioration of the subgrade and the slab edges. This loss of slab support accelerates the pumping of slab corners and leads to structural failure of the slab.

The intrusion of incompressible solids into the joint space causes even greater problems. Joints filled with solids are unable to close properly; consequently, extremely high stresses are built up within the slabs. Because of the uneven nature of the solid material that has infiltrated into the joint, nonuniform concentrated stresses in the concrete adjacent to the joint opening ultimately result in spalling and progressive disintegration of the concrete. Figure 1 shows a deteriorated armored joint in an expressway.

A recent research study conducted by the University of Mississippi indicated that approximately 80 percent of the States that use rigid pavements are troubled with pavement growth* (IIIA). The extreme growth movements which have been reported are the result of many factors, but the joints are considered to be a major contributory element. Joints filled with incompressible material are unable to close properly. Consequently, the compressive stresses may be relieved by a blowup in which a portion of the slab breaks away and moves upward (Figure 2), or the entire slab mass may translate. These translational movements are particularly destructive at the approaches to bridge structures. In many cases such movements result in split or tilted abutments and in bridges being literally pushed off their bridge seats. Figure 3 shows the abutment of a small structure which has cracked and tilted.

In bridge and viaduct structures, water infiltration through the joints is more important. Such structures are usually on at least a minimum grade, so that an open joint serves as a funnel which directs the flow of salt solutions onto bridge seats and pier caps. Damage from this source alone is costing the State highway departments hundreds of thousands of dollars annually in maintenance and repair. Figure 4 illustrates the disintegration of a bridge structure.

* Numbers in parentheses refer to the section designation in the bibliography, Appendix B.

Figure 1. Concrete disintegration adjacent to an armored joint due to incompressibles in the joint.

RESEARCH APPROACH

To obtain information on the state of the art, it was necessary to gather information from a wide variety of sources. A search of the current literature was performed and a questionnaire was distributed to the many different types of interested organizations. On the basis of the data gathered during these phases, personal interviews were conducted with personnel of various organizations where information of particular value was indicated. A feedback between these 3 data gathering phases of the work was valuable in uncovering sources.

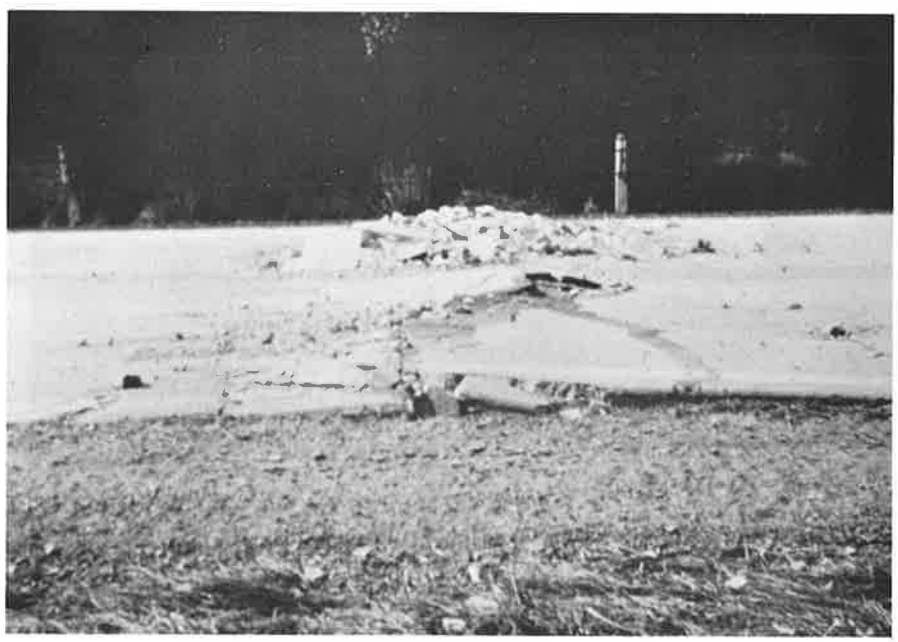

Figure 2. Concrete blowup.

Figure 3. Abutment cracking due to pavement pressure.

Questionnaires

Questionnaires were developed to determine current practices, research, and experimentation in joint and crack sealing. These were sent to State highway departments, turnpike authorities, and Canadian provincial highway departments. Those cities and counties having highway or engineering organizations, some 303 in number, were also canvassed. Other types of questionnaires were distributed to universities and research organizations. Questionnaires were also sent to sealant manufacturers to ascertain what products were available, to detect trends among the producers, and to measure their reactions to existing specifications.

Each survey questionnaire was examined and when it appeared that a respondent had a particular problem or interest, additional correspondence was initiated and in many cases a personal visit was made. Responses were then analyzed and correlated to determine current practices and the status of research performed or in progress. This permitted an analysis of trends with comparable surveys previously conducted.

Literature Search

The literature survey was conducted both manually and by automated information-retrieval methods. The following sources were searched for available information:

Rensselaer Polytechnic Institute Libraries
Engineering Societies Library, United Engineering Center
New York State Library

Figure 4. Concrete disintegration beneath an open bridge joint.

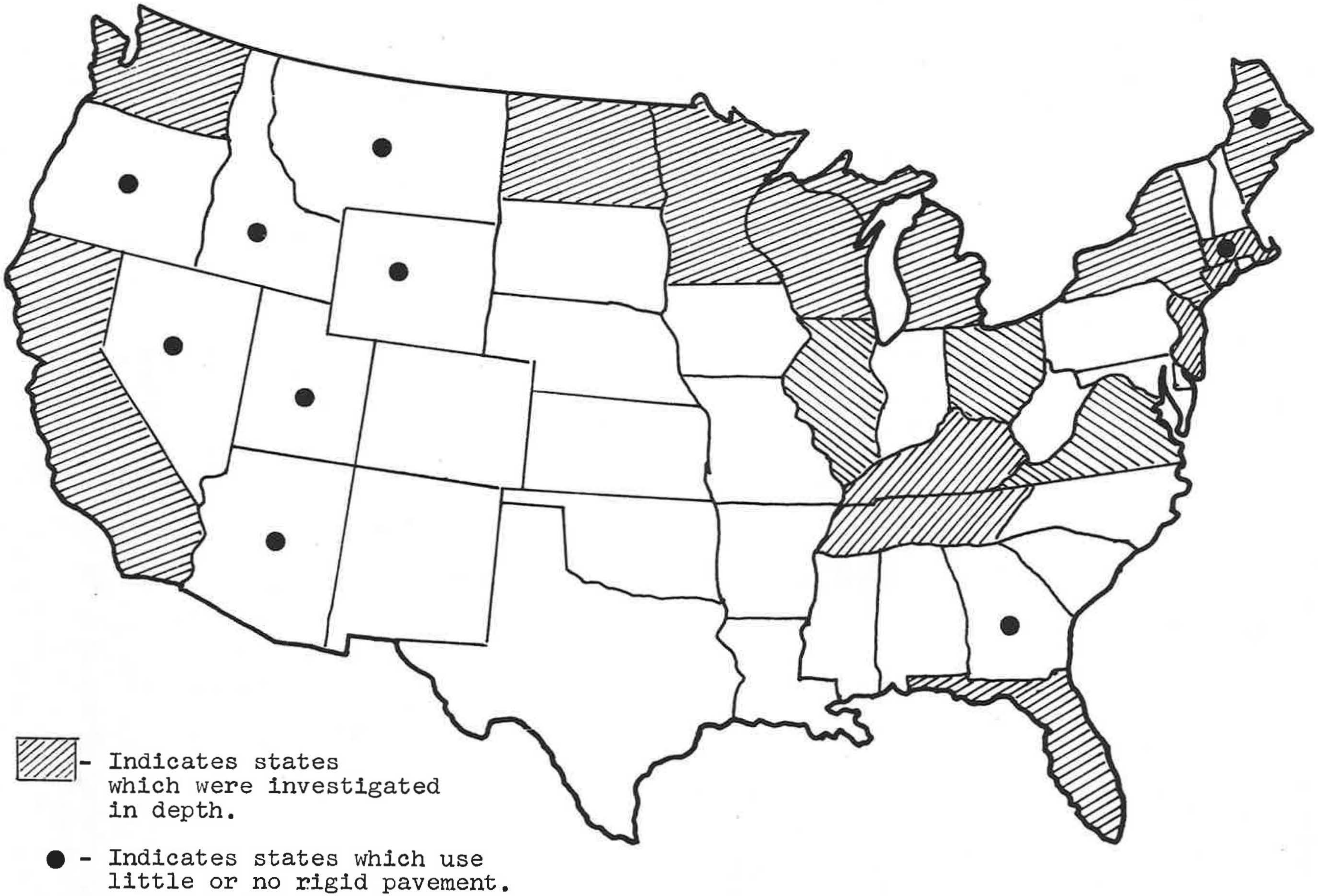

Figure 5. Geographic distribution of States investigated in depth.

Miller-Warden Associates—National Bituminous Concrete Association Technical Literature Survey
National Aeronautics and Space Administration—Institute of Aeronautics and Astronautics Literature Survey
Highway Research Information Service

The NASA search revealed many articles on exotic materials of possible future value, but which do not presently enter the highway picture. The Engineering Societies Library was especially useful in locating information published in other countries.

More than 700 articles of interest were located, examined, and classified for detailed study. Further evaluation reduced this number to 259 references of significant interest. These references, along with their classification, evaluation, and annotation criteria, are included as Appendix B. An existing annotated bibliography (IA-22) covers joint, crack, and undersealing materials. Because of the limited availability and the age of this bibliography, no entries were duplicated as part of the listings contained herein. A supplement to the 1951 bibliography, however, was issued in 1963. Because the supplement may not have received wide distribution, and because those entries are more current, selected entries were included as part of this report.

Interviews

Upon completion of the questionnaire survey and after much correspondence, meetings were held with the representatives of 17 State highway departments. The object of these meetings was to pursue further the questions raised by correspondence and to obtain opinions as well as direct answers to several pertinent questions. An attempt was made to cover all geographic areas which might present different aspects of the problem and to talk with those people who indicated special problems or interests. The States selected for further investigation are shown in Figure 5.

Personnel of 18 agencies, associations, and trade organizations were contacted, several of which made significant contributions. Although little current research on joint sealing was indicated by universities, 6 were contacted to investigate work on peripheral problems.

The producers of sealant material and equipment were the most cooperative and enthusiastic group contacted in this survey. Nineteen companies were selected as representative of the industry. A list of all States, agencies, associations, universities, and industrial organizations contacted during the interview phase of the work is included in Appendix A.

CHAPTER TWO

FINDINGS

FINDINGS FROM QUESTIONNAIRES

To gather data concerning joint-sealing practices and experience, questionnaires were sent to State highway departments, turnpike authorities, and city and county highway organizations. The data for States and turnpikes were comparable and, therefore, grouped for analysis. Sixty questionnaires were sent to these organizations, and replies were received from 50 (a return of 83 percent). Likewise, it was found to be appropriate to group cities and counties. Questionnaires were sent to 303 of these units. Replies were received from 208 (a 69 percent return). Of this number, however, only 139 cities and counties reported that portland cement concrete pavements were being used and this latter figure was used in the computation of the percentages that follow.

Tables 1 through 3 summarize some of the information obtained from the questionnaires. Where an organization permitted the use of more than one material, each is included. Table 1 shows the types of sealing materials currently used for pavement joints and for expansion joints in structures. The types of sealant failures observed are summarized in Table 2. Ten States indicated that they were conducting experiments or tests with sealant materials. Table 3 lists the materials that have been tried by the States and subsequently discontinued. The overwhelming majority of cities and counties, however, indicated that very little experimentation has been conducted, and consequently few joint-sealing methods or materials have been rejected. These organizations displayed only a lukewarm satisfaction with present methods.

FINDINGS FROM INTERVIEWS

Opinions of State Highway Personnel

During the course of investigation, personnel from 17 geographically distributed States were interviewed. These were engineers in top positions of the various highway departments—in the fields of maintenance, design, and/or materials. Some of the questions asked and the replies generated are presented in the following. Percentages are based on the 17-State sample.

1. Why do we seal joints? Are we protecting against water or against the intrusion of incompressibles?

   Seventy percent felt that incompressibles were the major problem. Bridge joints should be considered

TABLE 1

CURRENT USE OF SEALING MATERIALS IN PAVEMENT JOINTS AND EXPANSION JOINTS OF STRUCTURES

	PERCENT PERMITTING USE IN			
	PAVEMENT JOINTS		STRUCTURAL EXPANSION JOINTS	
TYPE OF SEALING MATERIAL	STATES AND TURNPIKES	CITIES AND COUNTIES	STATES AND TURNPIKES	CITIES AND COUNTIES
Hot-poured bituminous	68	79	36	59
Cold-poured bituminous	16	6	0	1
Cold-poured elastomers	10	4	18	4
Preformed sealants	10	22	10	14
Finger plates or open joints	—	—	30	14

separately, and water is the major problem in bridge joints. Two respondents questioned the value of sealing at all.

2. Is joint sealing a materials problem or a maintenance problem?

Thirty-five percent considered it as mainly a maintenance problem, whereas 30 percent thought of it as a materials problem. The remainder considered it the responsibility of both the departments concerned with maintenance and materials.

3. Are more studies of pavement movement necessary as part of a thorough joint-sealing research program?

Sixty percent felt that more movement studies were necessary. Several respondents made the point that there are many studies both published and unpublished already available. The need is to fill in the gaps with detailed studies.

4. Is a review of current specifications a necessity?

Ninety-five percent stated that a complete review was necessary.

5. Should the ultimate specification be a performance-type specification only, or should it contain some material requirements?

Sixty percent felt that the specification should be of the performance type.

6. Is there a blanket solution which will be applicable to the entire United States?

Ninety-five percent felt that there is no blanket solution, because different geographical areas have different problems.

7. There seems to be a definite trend toward the extruded-neoprene seal. Do you feel that this material is the final answer to the sealing problem?

Seventeen percent felt that this material was the final answer. The majority opinion seemed to be, "It looks promising, let's wait and see."

8. Is more education about the awareness of sealing problems a necessity?

Ninety-five percent stated that more education was necessary. Lack of communication between designers, maintenance personnel, inspectors, and producers was cited.

TABLE 2

TYPES OF FAILURES OBSERVED FOR JOINT-SEALING MATERIALS

	PERCENTAGE OBSERVING FAILURE	
TYPE OF FAILURE	STATES AND TURNPIKES	CITIES AND COUNTIES
Extrusion of sealant onto pavement	52	57
Surface cracking	38	20
Intrusion of dirt	58	35
Adhesion	52	12
Other	16	8

TABLE 3

TYPES OF SEALANTS THAT HAVE BEEN TRIED AND THEN DISCONTINUED

	STATES DISCONTINUING USE [a]	
TYPE OF SEALING MATERIAL	NUMBER	PERCENT
Hot-poured bituminous	6	12
Cold-poured bituminous	14	28
Cold-applied elastomers	16	32

[a] No rejection of sealants was indicated by 26 (52 percent) of the States. A noncommittal reply to rejection of sealants was made by 18 (36 percent) of the States.

General Comments

The following paragraphs are a compilation of the comments and discussions that resulted from interviews with personnel representing highway departments, sealant manufacturers, trade associations, and government laboratories.

Perhaps one of the greatest needs at the moment is education. Communication is weak. It takes cooperation between suppliers, designers, contractors, and inspectors to obtain good joints. The designer must provide a joint opening with the proper width and shape factors in relation to the slab length. The manufacturer must supply a quality material and the contractor must provide proper supervision and installation. Unfortunately some designers are not yet aware of the demands on, and the capabilities of, a sealant. As an example, a 60-ft slab will move approximately 0.4 in. as a result of a temperature change of 120°. With a joint ¼ in. wide, this means a strain of approximately 160 percent in a poured sealant. A preformed seal compressed to 50 percent of its original width before installation would also be rendered useless in this situation.

The opinion is sometimes expressed that contractors are responsible for most of the poor sealant installations. However, most of the responsible State officials feel that the contractors do conscientiously try to follow the specifications. The contractors do not (and should not be expected to) keep up with the technical literature. Salesmen keep them abreast of new materials. In general, they show no heavy preference for one material type.

Mistakes do happen on the job, sometimes because some contractors are not fully informed about individual materials which may be specified and sometimes because of difficult field conditions. It is also true that the joint sealing is a minor percentage of the total construction contract. Consequently, brokers selling package deals including sealants, dowels, mesh, can often force the reputable sealant applicator out of the picture.

Type of Specifications Desired

During the interviews of State highway personnel and sealant manufacturers, a basic philosophical question to be resolved was whether a sealant specification should be a performance type only or whether the specification should contain at least minimal material requirements. Sixty-one percent of the State highway engineers felt that a performance-type specification was sufficient, whereas almost 90 percent of the sealant manufacturers interviewed were in favor of this type of specification. The following comments are typical of the replies to this general question.

Specifications should be of the performance type only.

"We are only interested in the performance of a finished product. If it will do the job, we don't care what it's made of."

"It is the responsibility of the specifying authority to write a tight specification. We want results."

"This is a tough competitive market. If you put a materials requirement in the specifications, we have no incentive to develop new materials. You are killing technological progress."

A materials requirement is needed in the specifications.

"There are too many sharp operators in this world who can beat a performance specification. I want to know what I'm buying."

"I want a performance specification, but I want at least a minimum requirement regarding materials to keep out the junk."

"If you don't put a materials requirement in the specification, I can't competitively make a quality sealant."

EXPERIENCE WITH MATERIALS AND PROBLEMS

The experiences and subsequent evaluation of sealants are grouped and presented in the following by material type.

Hot-Poured Materials

In general the States have shown a dissatisfaction with the hot-poured rubber asphalts. In many cases the attitude is almost one of resignation. On the other hand, Massachusetts reports one case of reflection cracking which was resealed in 1958 and is still in good shape. One manufacturer has recently developed a much improved hot pour, which on the basis of 1½ years of use in Minnesota looks excellent. Several other States are currently investigating this material.

Connecticut reported having cut out sections of an older asphaltic sealant to check embedment of incompressibles into the body of the sealant. Laboratory analysis revealed that the specimens were approximately 80 percent sand. These specimens were well over 5 yr old. The Province of Quebec has many installations of hot-poured materials and is satisfied. The Province of Manitoba reports about 50 percent success with hot-poured materials, but Ontario has rejected the hot-poured materials as unsatisfactory.

Cold-Poured Elastomers

The New York State sealant test results showed almost universal failure of the elastomeric systems in the first 2 winters. Almost every conceivable type of failure was seen.

Adhesion and cohesion failures, bubbling of the urethanes, and surface crazing were all noted. These materials were all installed by manufacturers or their representatives in ⅜-in. joints spaced at 60 ft 10 in.

One manufacturer, however, reports two small bridge installations of polysulfide which look good after 3 yr, and another reports a machine-mixed polysulfide functioning well in longitudinal joints after 5 yr of service.

Many States, including Kansas, Nebraska, New York, and Pennsylvania, have rejected the elastomers on the basis of trial installations. The usual report is failure in the first 2 winters. Rhode Island has taken another look at the problem and has rejected the elastomers for joint spacings greater than 60 ft. Hawaii uses a 30-ft joint spacing and is well satisfied with the polysulfide sealants. Texas uses a 15-ft joint spacing and has rejected the elastomers because of poor weathering. The Province of British Columbia uses polysulfide for bridge expansion joints.

Preformed Seals

One of the Connecticut research engineers considered the chief advantage of the neoprene seal to be "cosmetics." He stated that we need more experience to prove out this material, but that it cannot be denied that it gives the neatest looking joint of any known sealant. New Jersey is still working on an exceptionally thorough study of the neoprene seals for expansion joints in bridges. They report that this seal does not give a watertight joint at this time. However, they do feel that this type of seal is the best solution for the bridge joint. New York reports a general satisfaction with the neoprene seals after 5 years.

Crack Sealing

Crack sealing, generally, is considered a maintenance responsibility and is not subject to the same controls as new construction. The New York State Thruway uses a coal-tar crack filler, as do many other State authorities. The Canadian Province of New Brunswick seals with an asphalt emulsion and sand. Saskatchewan has rejected hot-poured material and seals annually with a cutback asphalt. Sand is sometimes used.

Cost Factors

Costs of sealant installations, of course, vary widely from State to State. Bid prices cover a wide range, and in many cases they are a part of a total contract and are consequently difficult to isolate. The costs break down into 3 general classes: joint sealing (new work), joint resealing, and crack sealing.

Cost figures for new work are hard to ascertain because such items as joint sawing and cleaning may or may not be included in the bid price for joint sealing. Representative figures are given in Table 4.

Resealing of joints, in addition to the requirements for new work, depends on the type of material being used and the type of material already in the joint. Sealing with a dissimilar material, of course, requires a very thorough job of cleaning. Representative costs for the resealing of joints are given in Table 4. These figures include $0.07 per foot for joint cleaning.

TABLE 4

REPRESENTATIVE COST FIGURES FOR JOINT-SEALANT MATERIALS

	COST ($/FT)	
TYPE OF MATERIAL	ORIGINAL INSTALLATION	RESEALING OF JOINTS
Hot-poured rubber asphalt	0.10–0.30	0.20–0.35
Elastomeric	0.40–0.60	0.30–0.50
Preformed	1.00–3.00	1.00–4.00

SEALANT MATERIALS

Requirements for Sealant Specifications

All sealant specification requirements may be broken down into two classes of properties: (1) physical-chemical, such as flow, tackiness, period of cure, viscosity, toxicity, resistance to ozone, and hardness; (2) kinematic or performance properties, such as extension of bond, peel, compression set, and resilience.

There is very little dissatisfaction with the physical-chemical properties. Tests and methods (mostly through ASTM) are currently available for evaluating these materials. In any specification revision, these requirements will have to be carefully reviewed as to applicability to sealant types, but the test methods do exist. There is, however, almost uniform dissatisfaction with the kinematic requirements of the specifications. Most State specifications are modeled after a parent ASTM or Federal Government specification. Some of these parent specifications and their requirements are given in Table 5. The various specifications reviewed are listed by sealant type in Tables 6 through 8. Many other manufacturers' specifications were also studied, but only those specifications having official status are listed in the tables.

Suggested Revisions to Specifications

During the course of the investigation, the following suggestions were made for revising current specifications:

1. Weatherometer data for accelerated aging of specimens need further field corroboration to make them really effective.
2. Recovery tests should be revised for all types of sealants. The rate of recovery is important.
3. Most specifications have been written around a successful material and may not be meaningful for other materials.
4. Specifications should be more definite about application equipment.
5. The ultimate specification should be written specifically for highway work. It should be of the "model law" type and each State can modify to suit its own conditions.
6. Realistic specification requirements are a must. The relationship between climate and slab length is important.
7. Specification requirements which indicate a single source of supply should be eliminated.
8. Rewrite the provisions for shape and recovery of the preformed seals. Include a measure of sealing pressure.
9. The use of a national laboratory or policing system independent of the producers has been suggested.

Material Tests and Studies Needed

The following lists some of the tests and studies which were suggested by the correspondents in this survey.

PREFORMED SEALANTS

1. Development of an improved flex-fatigue test.
2. An investigation of the watertightness of the seal.
3. A study of such parameters as shape, wall thickness, and web configuration.
4. Development of a definitive set of chemical-physical tests to prevent competition from downgrading the raw materials.

BULK-TYPE SEALANTS

1. Improvement of the peel-adhesion test.
2. A study of the work hardening of polymeric-type sealants.
3. Development of a joint-testing machine which can program the results of pavement-movement studies.
4. Development of a measure of resilience control.
5. A fatigue study of polymer-type sealants.
6. A thorough study of adhesion of both the polymer types and the hot-poured rubber asphalts.

TABLE 5

REQUIREMENTS OF VARIOUS SPECIFICATIONS

SPECIFICATION	SEALANT TYPE	TESTS REQUIRED
Federal SS–S–170	2-component elastomer, jet-fuel resistant	Penetration test; Bond test
ASTM D1850–61T	Cold-applied sealer, 1- or 2-component	Penetration test; Bond test
Federal SS–S–158a	Cold-applied sealer, solvent type	Bond test
Federal SS–S–00195a	2-component elastomer, machine mixed	Penetration test; Bond test; Recovery test
Federal SS–S–00200c	2-component elastomer, machine mixed, jet-fuel resistant	Penetration test; Bond test; Recovery test
Federal SS–S–164	Hot-applied sealant, rubber asphalt	Penetration test; Bond test
ASA 116.1	2-component polysulfide (for buildings)	Adhesive strength—initial Adhesive strength—after immersion Adhesive strength—after heat aging Adhesive strength—after temperature cycling Recovery test
Federal TT–S–00230	1-component synthetic rubber (for buildings)	Penetration test; Bond test; Peel adhesion test

TABLE 6

COLD-POURED SEALANT SPECIFICATIONS REVIEWED

DESIGNATION	MATERIAL DESCRIPTION
ASTM D1850–61T	1- or 2-component (no composition restriction)
SS–S–158a	Asphaltic; solvent type
SS–S–156	Emulsion type (no composition restriction)
TT–S–00230	1-component; synthetic rubber, for buildings
SS–S–170	2-component; synthetic rubber; jet-fuel resistant
SS–S–00195	2-component; polymer type; machine mixed
SS–S–159b	Multiple component; mastic type
SS–S–168	2-component; bituminous; mineral filled (for sewer pipe)
TT–S–00227a	2-component; polymer type (for buildings)
SS–S–00200C	2-component; polymer type; jet-fuel resistant; machine mixed
ASTM D1852–61T	2-component; polymer type; jet-fuel resistant
ASA A116.1–1960	2-component; polysulfide type (for buildings)
City of Seattle	2-component; epoxy polysulfide type (for concrete bridges)
California 62–F–29–30	2-component; polymer type
Massachusetts	Rubber asphalt; mastic and emulsion types (cracksealing)
U.S. Navy Nav docks 46 Yd	Liquid type; Other federal specifications referenced as to use areas
Bureau of Reclamation	Rubber asphalt; solvent type

7. A study to develop the optimum rubber content in the hot-poured rubber asphalts.
8. Determination of the optimum force-elongation-adhesion relationship for concrete substrates.
9. A study of the combined tension-shear stresses in skewed joints.
10. A study of the effects of concrete admixtures on sealant performance.
11. Development of a rapid, nondestructive test for quality control. This test result should be capable of being compared with the original manufacturer's quality control data.

EQUIPMENT

Laboratory Testing Equipment

When field performance tends to break down under uncontrollable parameters, it is natural to turn to the laboratory where controlled conditions will yield undisputed facts. Because laboratory tests are used to set the limits in specifications, one often considers the results as sacrosanct. Unfortunately this is hazardous, as was shown by Tons (IB-20) in his paper on comparative testing of joint sealers. Sixteen laboratories tested the same three hot-poured, rubber-asphalt sealers in accordance with Federal Specification SS-R-406C.* The mortar blocks and samples were all provided by a centralized source. Nevertheless, the results of the tests did not agree. Material passed by one laboratory was rejected by another, and so forth.

Much of the equipment used in laboratory work is standard, such as ovens, penetrometers, and tensile-testing ma-

* Now Interim-Federal Test Method Standard No. 210.

chines. However, many specialized pieces of equipment have been constructed for various aspects of sealant work. A fairly broad sampling of this equipment is listed in the following, which does not attempt to delineate all the specialized pieces of equipment which have been constructed, but is representative of the types of equipment which have been developed.

BOSTIK TESTER

The testing machine built by Bostik Limited of England was designed to subject samples of sealants to cyclic deformation. The movement is applied in an incremental fashion in short steps alternating with longer stationary periods. The capacity is 6 specimens at a time on each unit; and the machine is equipped with 3 units, 2 for extension and compression cycling, and 1 for shear.

DEMATTIA TESTER

The DeMattia tester has long been used in the rubber industry to evaluate the resistance to cracking produced by extension or bending. It operates at constant speed under load, giving several hundred flexing cycles per minute. It is not generally applicable to testing sealants because it operates at too fast a cycle, it stalls with hard stock, and it is difficult to accurately set and hold a specimen.

DOMINION TESTER

Currently in development by Dominion Rubber Co. of Canada, this tester should make a significant contribution. A compression-extension tester, it will take 24 test samples, each 6 in. long. The joints may be extended and compressed in unequal amounts at the same time, but the total movement will be the same for all joints in any one cycle. An environmental chamber will be provided, capable of supplying temperatures between —40° and +160° F. The long-range objective is to continuously change the environment temperature to correspond with the test-sample cycling.

SIKA TESTER

The Sika tester (shown in Fig. 6) was designed for compression-extension testing and has a capacity of six 3-in.-long specimens. It is wheel mounted, which facilitates movement from laboratory to cold room. The device is built entirely of aluminum and stainless steel to prevent corrosion from condensation.

PCA SEALANT TESTER

This tester will test twenty 4-in.-long specimens. It is adjustable by micrometers and limit switches and includes pressure cells to give stress as well as strain. The unit is wheel mounted and may thus be placed in an environmental chamber.

ORD TESTER

The testing machine developed by the Ohio River Division Laboratory of the U.S. Army Corps of Engineers is probably the largest unit in use. It will test 120 specimens in a controlled environment and can be programmed for a wide range of movement.

RPI CREEP APPARATUS

The equipment was developed at Rensselaer Polytechnic Institute with research funds provided by Thiokol Corporation. It plots the creep and recovery of elastomeric sealants. As may be seen in Figure 7, three 6-in.-long specimens may be tested in a controlled environment.

BUREAU OF RECLAMATION JOINT SIMULATOR

This machine (Fig. 8) was designed for testing canal sealants. One-ft-long specimens that can be immersed partially in water can be tested. The device is installed outdoors, and joint movement is actuated by black plastic rods subjected to ambient conditions.

TABLE 7

HOT-POURED SEALANT SPECIFICATIONS REVIEWED

DESIGNATION	MATERIAL DESCRIPTION
SS-S-00164	Asphalt; with or without rubber
ASTM D1190-64	Elastic type (no material restrictions)
ASTM D1854-61T	Elastic type; jet-fuel resistant
SS-S-171	Asphalt; mineral filled
SS-S-169	Asphalt, coal tar, or plastic; mineral filled (for sewer)
SS-S-167b	Jet-fuel resistant (no material restrictions)
New York—Addenda No. 14	Rubber asphalt
New Jersey	Oxidized base emulsified asphalt; with neoprene

TABLE 8

PREFORMED SEALANT SPECIFICATIONS REVIEWED

DESIGNATION	MATERIAL DESCRIPTION
ASTM C509	Cellular elastomeric preformed gasket
AASHO-ARBA Draft	Preformed elastomeric compression seal
ASTM D994-53	Bituminous mastic composition between layers of felt
ASTM D1752-60T	Sponge rubber, cork, and self-expanding cork
ASTM D1751-65	Cork or cane fiber with bituminous binder and felt
ASTM D545	Closed-cell organic foam
Concrete Joint Institute Draft	Cellular plastic; polyurethane, polyethylene, or PVC
ASTM Draft	Preformed neoprene
New Jersey	Preformed neoprene
British Columbia	Preformed neoprene

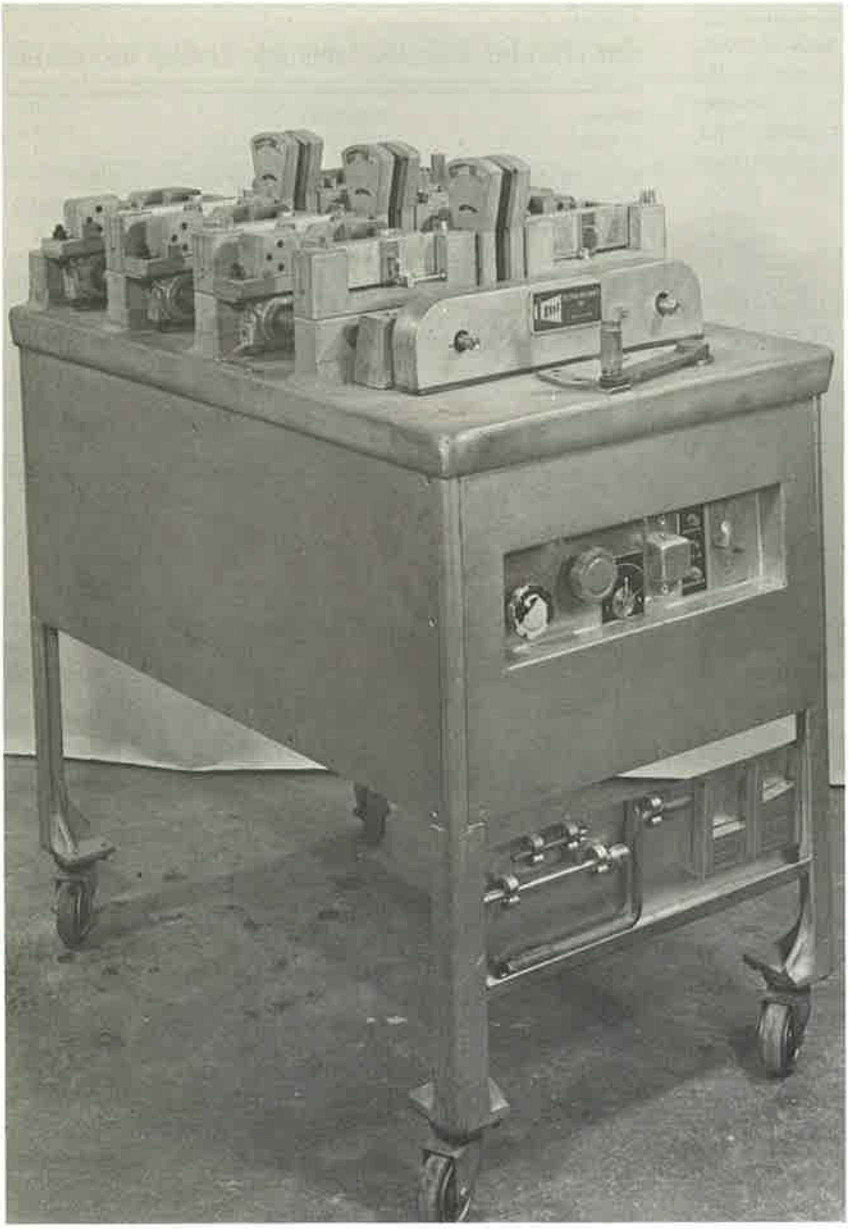

Figure 6. The Sika extension-compression testing machine.

ATLAS WEATHEROMETER

The Weatherometer is a controlled-environment chamber for the accelerated aging of laboratory-sized specimens. This apparatus is widely used for testing paints and coatings as well as sealants. A large number of specimens may be tested, as may be seen in Figure 9.

Installation Equipment

The sealant cannot function properly unless both the joint and the material are properly prepared and installed. Each type of sealant has its specific installation requirements; typical installation equipment is described in the following.

PREFORMED SEALANTS

One of the great assets of the preformed seal has been its ease of installation. The equipment for installation in the early days consisted of only a hand roller formed with a center-flange wheel and a simple spray tank for the lubricant-adhesive. Unfortunately, applications of the seal with the hand roller did result in some stretching of the material which caused a change in cross section. Automatic installation equipment has recently been developed to combat the stretching problem. With this equipment, a premeasured length of seal is fed to the machine and is automatically installed to the proper depth in the joint. One such machine, made by the D. S. Brown Co., is currently in use, and other models are entering the market.

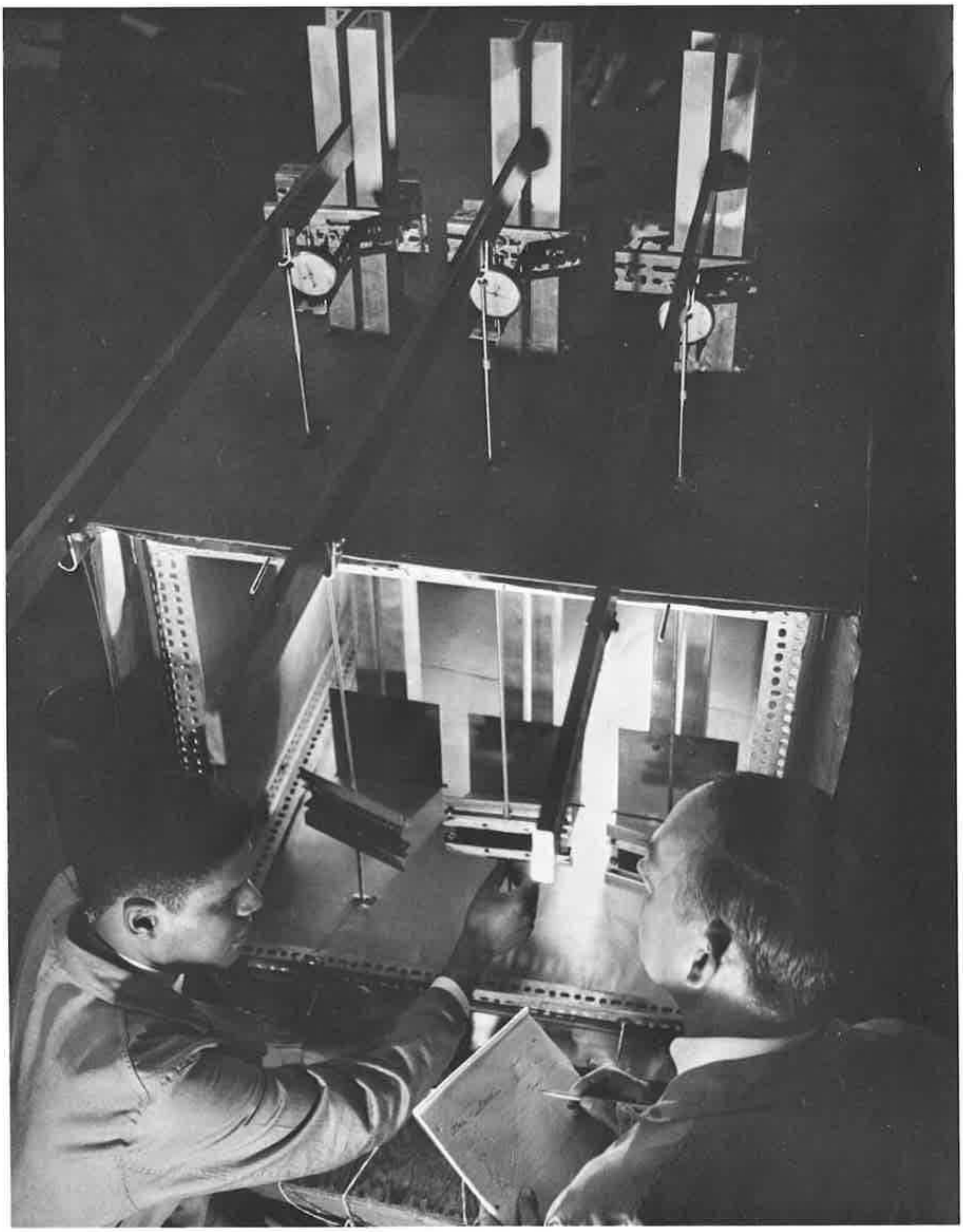

Figure 7. The RPI environmental creep apparatus.

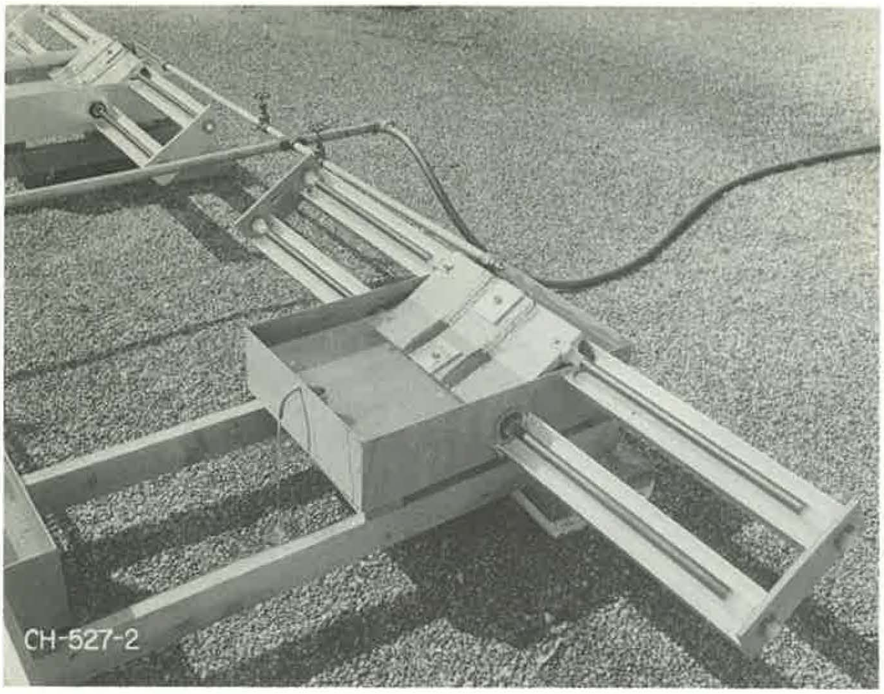

Figure 8. Bureau of Reclamation joint simulator.

HOT-POURED SEALANTS

Equipment for installation of the hot-poured sealant consists basically of a heater and either a gravity flow or pump system to feed the material into the joint. Unfortunately, the old fashioned "tar kettle" is often used as the heating apparatus. Several makes of very good jacketed heaters with temperature controls are currently available. Many of these units are of the oil-bath type, and almost all are wheel mounted.

COLD-POURED ELASTOMERS

The cold-poured, polymer-type sealants can be manufactured as either hand-mixed or machine-mixed materials. The machine-mixed materials include some of the fillers in with the curing-agent component, so that the volumes of the 2 components are approximately equal. Attempts to hand-mix this type of material have almost invariably resulted in improper mixing.

The apparatus for mixing and applying this type of material is a dual-tank, pressure-fed system in which the 2 components are accurately metered and mixed at a mixing head adjacent to the nozzle, and the sealant is pressure fed into the joint. One machine of this type is the "Allied Machine," now manufactured by the Boardman Company. The hand-mix elastomers are furnished as 2 components. The resin component contains all, or almost all, of the fillers. The curing agent may be furnished in the form of a powder or as a curing paste which contains a minimal amount of filler. The proportions are roughly 15 parts of curing agent to 100 parts of polymer. This proportion varies with the amount of fillers used. This type of sealant is generally mixed with a paddle attachment on an electric drill. Components are furnished in different colors, so that color blending is an indication of thorough mixing. This type of material can be placed in the joint by refillable caulking-type guns, or it can be poured directly from the can into the joint.

PRESEALED JOINT

The presealed joint is installed by a unit which immediately follows the paving train. This apparatus is approximately 12 ft wide and rides the steel form on flanged wheels. The complete joint unit is vibrated into place in the wet concrete. Two variations of this unit are currently being placed in test installations. Figure 10 shows a presealed joint being placed.

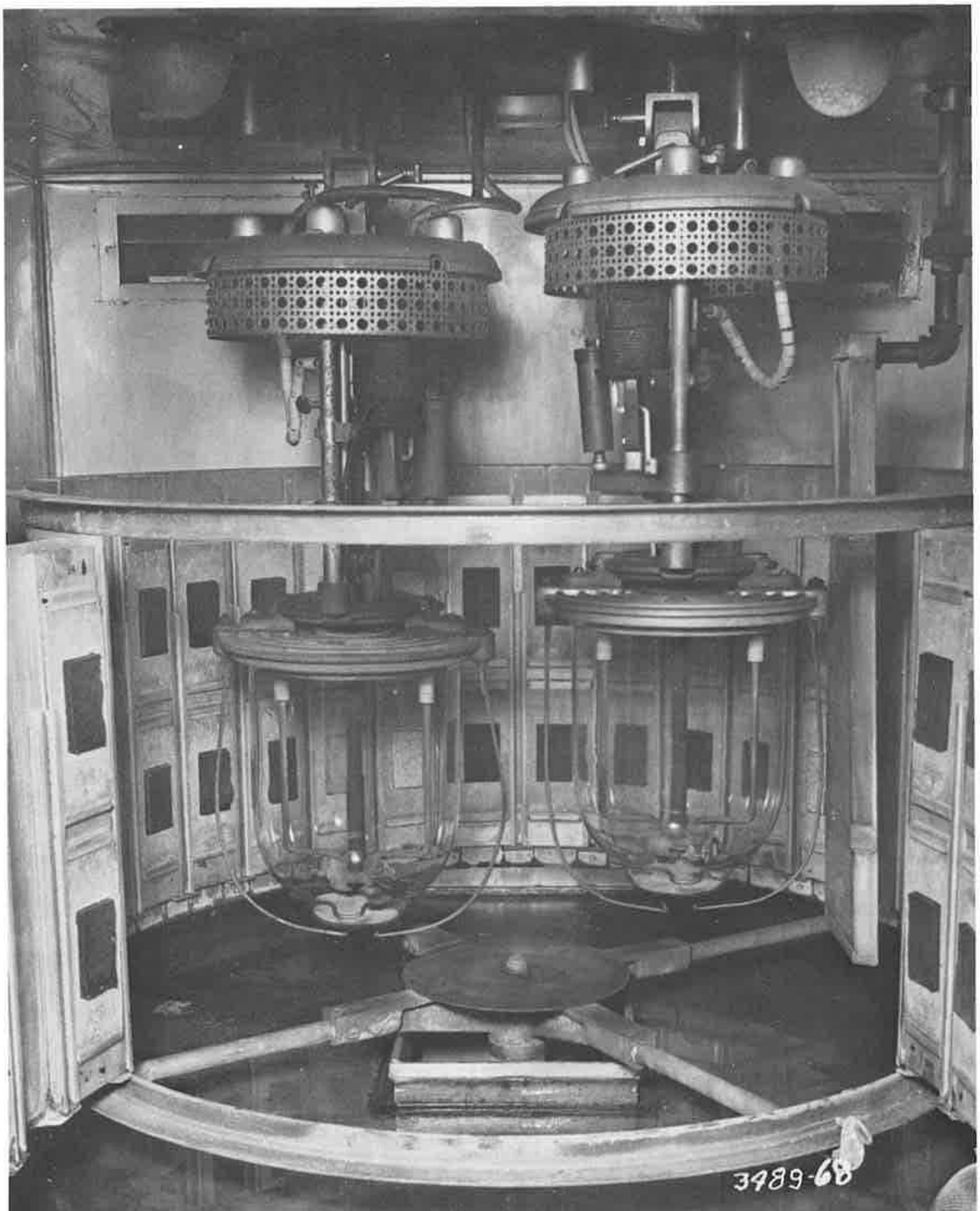

Figure 9. A Weatherometer.

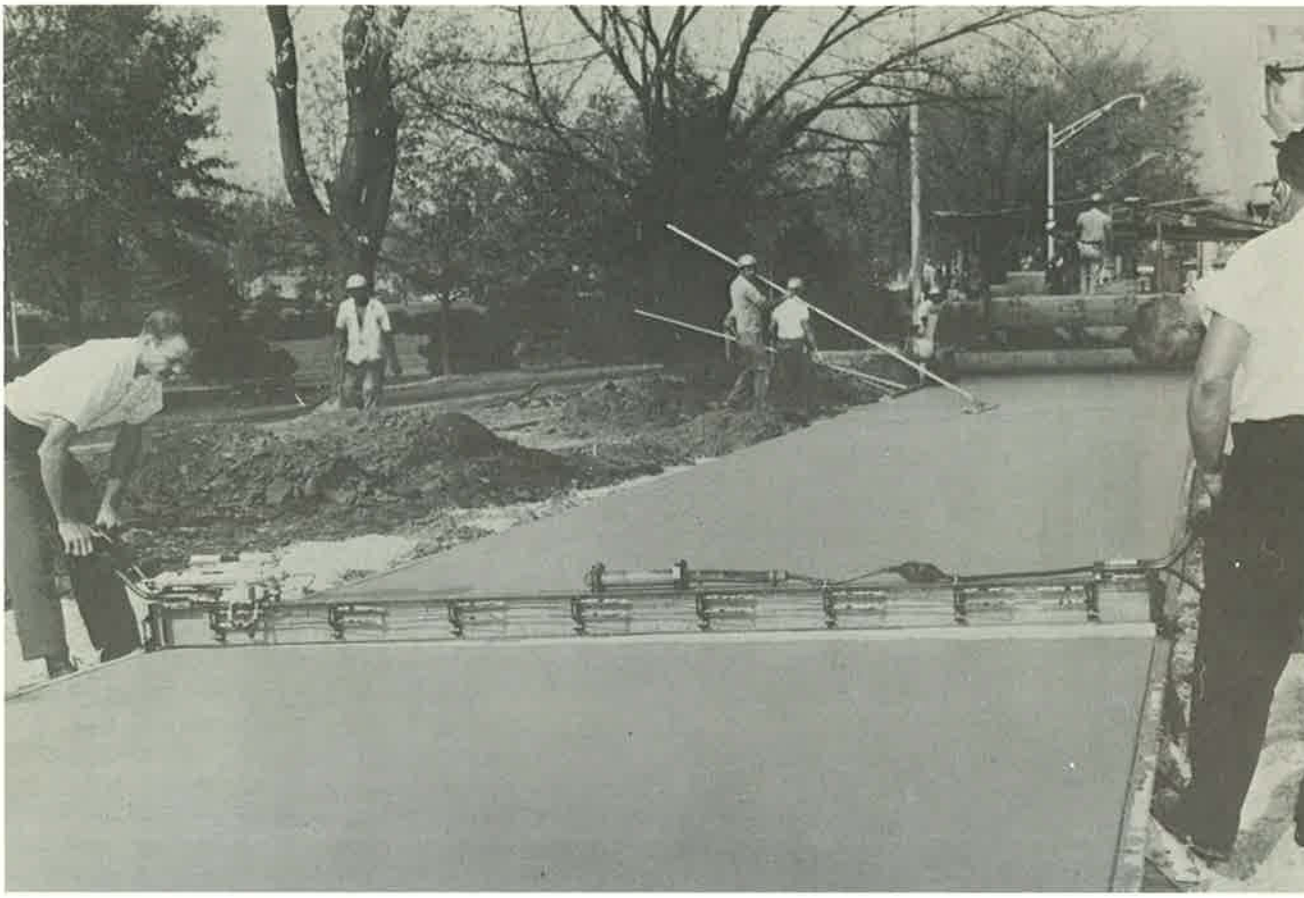

Figure 10. Installation of a presealed joint.

CHAPTER THREE

INTERPRETATION AND CONCLUSIONS

GENERAL

The joints in rigid pavements are usually sealed to prevent the intrusion of foreign material, water, and chemical deicing solutions. There are, however, alternate solutions to the joint problem. It is possible to eliminate the joints by the use of continuously reinforced pavement. At the present time, continuously reinforced pavements are considered economically feasible only for the highest type pavements. However, the additional cost of sealing and resealing joints over a period of years may well bring the total life-span cost of the continuous pavement into a more competitive price range.

There are also some engineers who question the necessity of sealing joints. Whereas the bulk of the evidence seems to indicate that joint sealing is vital, there may be areas where this dissenting opinion is justified. By building slabs on well-drained subgrades, the deleterious effects of water in the joints are reduced. Slabs built on stabilized subbases should show less intrusion of incompressibles from the bottom of the joint. In extremely dry areas, the corrosion of load-transfer devices is only a minor problem. Therefore, it is possible that in some areas open joints and a cleaning program are an economically feasible alternate to joint sealing.

BEHAVIOR OF THE JOINT

Every structure, including pavement slabs on grade, expands and contracts because of changes in temperature. As a pavement moves, the joint opens and closes, and the sealant must perform its primary function of sealing while accommodating the change in width of the joint opening.

The sealant, therefore, must be capable of extension and compression, and yet still maintain its bond to the joint wall. It must also be tough and elastic enough to prevent puncture or penetration by sharp stones and road dirt. Moreover, the sealant must perform these functions while being subjected to extreme temperature changes.

The movement of a pavement slab is a function of many variables. Among these factors are type of joint, size of joint, length of slab, type of subgrade, type of load-transfer device, range of temperature, and type and volume of traffic. The joint size and slab length should be interrelated. The joint width must be related to the slab length so that the change in joint size due to normal thermal changes will not be excessive. The movement of pavement slabs is generally assumed to be a slow, uniform process which bears a direct relationship to change in temperature. However, recent experimental work has shown that some slabs tend to move in a nonuniform, jerky fashion.

This incremental movement depends on the efficiency of the load-transfer device and on the frictional resistance between slab and subgrade and between slab and shoulders. The temperature change builds up stresses in the slab. Under some conditions, this buildup continues until the stresses exceed the frictional force between slab and subgrade. At this point, a short incremental movement of the slab begins.

Pavement slabs are also known to warp and curl because of temperature and moisture changes. It has been shown that the temperature of the slab-subgrade interface shows little variation as a result of fluctuations in the ambient air temperature. This is not true of the pavement surface. Under exposure to a "warm" sun, the surface temperature of the slab may be 30° to 40° F higher than the temperature at the bottom of the slab. The tendency of the top of the slab to expand while the bottom remains at a constant length causes the slab to arch upward away from the subgrade. At the other end of the temperature scale the situation is reversed; the slab tends to dish upward at the ends an amount dependent on slab length. This curl causes a rotation of the sealant material about its longitudinal axis. Curling of the slab is extremely important when related to traffic loads. Truck traffic passing over a typical contraction joint in the early morning hours when the slabs are dished upward causes much larger relative vertical movements between slabs than occurs later in the day. This vertical movement is quite small, but considered in terms of a traffic volume which may include several hundred trucks a day, it presents a great potential for fatigue failure of a sealant.

The movement of the bridge expansion joint is generally greater in magnitude than the pavement joint because the structure lengths are generally greater. Because of inertia and dirt at the bearings, the bridge also tends to move in a nonuniform fashion with temperature change. Furthermore, the bridge joint is also subjected to rapid expansion cycling because of deflection of the structure under traffic loading. With some of the span lengths in use today, a sealant material may be extended as much as 50 percent of its total annual extension every time a 20-ton truck passes over the structure. In many cases the bridge joint is skewed, so that the sealant is strained in the longitudinal as well as in the transverse direction.

The movements of longitudinal pavement joints are not nearly as severe as those of the transverse joints. Longitudinal joints are subjected to shear resulting from traffic and differential transverse movements of abutting lanes. Sealant materials in longitudinal joints, however, have shown far better performance records than the materials placed in the transverse, or working, joints.

In the past there have been many studies made of pavement movement. Many data on the gross movement of pavements were collected at the AASHO Road Test. Many States, such as New Jersey, Kentucky, New York, and Connecticut, have kept records of the movement of test pavements. The Portland Cement Association has cooperated with several States in movement studies. However, 60 percent of the State representatives interviewed felt that more detailed studies should be made to fill in the gaps in the existing knowledge. The majority of those interviewed showed an interest in specific aspects of pavement movement, such as rate of movement. The effects of subgrade friction and the effectiveness of aggregate interlock must also be considered.

Most of the records of pavement movement which are available indicate that slab movement is not uniform. In any series of contraction joints, the sequence of cracking is important. One joint may not crack through, or it may subsequently freeze up so that the adjacent joints have to accommodate the extra movement. The time of sawing for contraction joints is also important. Joints should be sawed before drying shrinkage stresses become too high.

The design of the joint opening and the time of sealing are both quite important. The width of the joint opening must be related to both the slab length and the temperature range so that the sealant material will not be overstressed. The depth of the sealant material in the joint affects the strain in the sealant material. Tons (IB-21) has shown that the depth of the sealant should be one-half the width to reduce the strains to a minimum.

In the normal contraction joint which is sealed promptly in new construction, the sealant material is placed only in tension under cyclic joint movement. In resealing work, however, the sealant material may be cycled into both tension and compression movements, depending on the temperature and the condition of the pavement.

CONSEQUENCES OF SEALANT FAILURE

When pavement joints are not properly sealed, water and incompressible solids can enter the joint. Over 70 percent of the respondents in this survey feel that the incompressible solids are the more serious problem. This incompressible material can be forced into the body of a sealant (see Figure 11), or it can work its way down beside the sealant once a failure has occurred. Joints filled with incompressible solids are unable to close properly, consequently extremely high stresses are built up within the slabs. Because of the uneven nature of the solid material that has infiltrated into the joint, nonuniform concentrated stresses in the concrete adjacent to the joint opening result in ultimate spalling and progressive disintegration of the concrete.

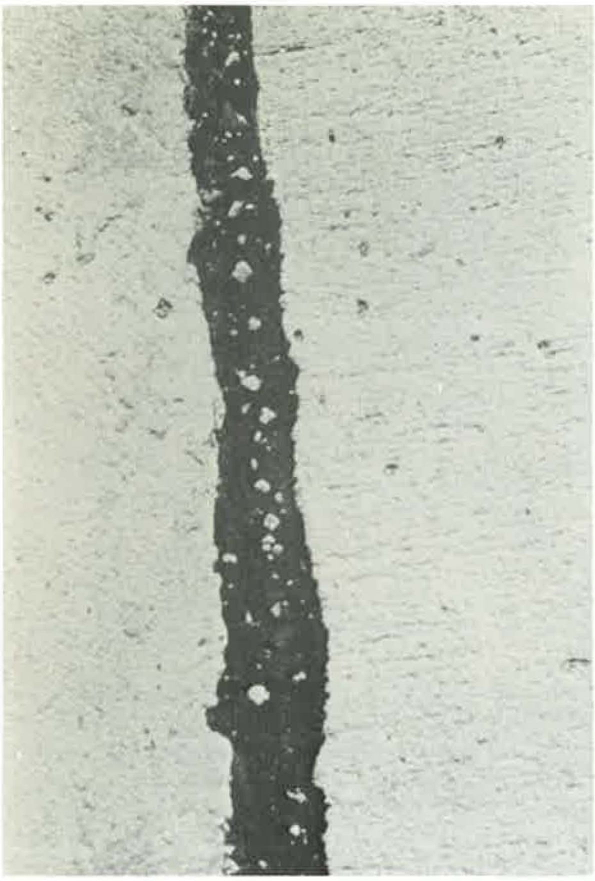

Figure 11. Embedment of solids into the body of a sealant material.

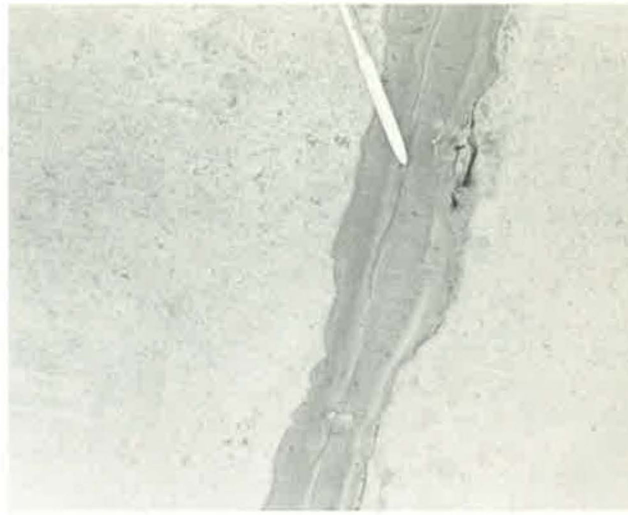

Figure 12. Spalled concrete adjacent to sealant.

Figure 12 shows a spalled joint. Spalling is usually considered to occur at the top surface of the pavement. However, recent studies and field observations in both New York State and Connecticut have shown that considerable spalling also occurs at the bottom of the normal contraction joint. As slabs move under the action of thermal changes, the opening and closing of the joint scoops up granular material from the subbase into the bottom of the joint opening. This foreign matter causes localized stress concentrations, which result in large amounts of spalling at the bottom of the joint. The resulting loss of bearing area between the adjacent surfaces of the concrete slabs sets up extremely high stress concentrations as additional material enters the joint, thereby causing crack patterns to form adjacent to the joint. Joints filled with incompressibles make it impossible for the slabs to move in a normal fashion. Consequently, compressive stresses may be relieved by a blowup, in which a portion of the slab breaks away and moves upward, or the entire slab mass may translate. These translational movements are affected by other factors, but the nature of the joints is considered to be a major contributory element. These translational movements are particularly destructive at the approaches to bridge structures. In many cases, such movements result in split or tilted abutments and in bridges being literally pushed off their bridge seats.

Water in the joints, especially in conjunction with highway salt, corrodes the load-transfer device and inhibits proper slab behavior. Water in sufficient quantity tends to soften and wash out subgrade material, thus accelerating the pumping of subbase material and the eventual cracking of slab corners and ends. Water is especially critical in bridge deck joints, because the open joint directs the flow of salt solution onto bridge seats and pier caps, causing extensive damage, as may be seen in Figure 13. In bituminous pavements, ice lenses forming at the bases of cracks are partly responsible for the heaving of these pavements.

TYPES OF SEALANT FAILURES

Under these various field conditions, the sealant may fail in any of several ways, as shown in Figure 14. The adhesive failure is simply a loss of bond between the sealant and the joint wall under a tensile load. The cohesive failure is a tearing of the sealant material, also caused by tension. A spalling failure of the concrete at the joint face, even though localized, breaks the continuity of the sealed joint and often results in a peeling-type adhesive failure the next time the joint opens. The extrusion type of failure occurs under the compressive action of the closing of the joint. A portion of the sealant material is extruded above the pavement surface, and, under the action of wheel loads, is then folded and flattened onto the pavement surface and cannot recover. Intrusion failure occurs as a 3-step process—a sealant extends and necks down, and then the pocket thus formed fills with road dirt which is entrapped within the sealant mass as the joint closes. The actual failure generally occurs during the next extension. For materials such as the polysulfide sealants, which exhibit stress relaxation and flow, a viscous tension failure can occur when the joint is extended and held open. Under these conditions, the sealant extends and over a period of a few day's will flow and stress-relieve itself until the sealant has relaxed into equilibrium in its new shape. During the next compression cycle, the material does not return to its former rectangular shape, but instead buckles and is flattened by traffic as with the ordinary extrusion failures. A similar type of viscous failure occurs under compressive loading. When the sealant is compressed and held, the sealant stress-relieves itself. During the next tensile loading, the sealant yields at the minimum cross section, which is adjacent to the joint interface. This high stress adjacent to the joint wall leads to loss of adhesion. Figure 15 shows a typical adhesive failure.

The preformed-gasket type of sealant is subjected to 2 types of failure. The first is compression set, in which the preformed sealant is compressed by the action of joint closing and is then held in this position for some time. Stress relaxation thus takes place, so that when the joint opens the sealant material remains bunched up and leaves an opening for the penetration of water and other incompressible materials. The other major difficulty with preformed seals is the inability of the sealant material to stay in the joint in its proper position as the joint works under the action of traffic. In some instances, progressive intrusion of dirt and incompressibles on top of the preformed sealant has forced the preformed sealant down into the bottom of the joint. In other cases, shearing action (the working of the two interfaces of the joint relative to each other) has worked the preformed sealant loose, so that the material was extruded upward out of the joint. There are very few reported material failures, such as tearing and splitting, with the preformed gasket materials.

Figure 13. Salt and water damage to a bridge column beneath an open joint.

MATERIALS

The materials currently in use for joint and crack sealing may be separated into 3 broad categories, the hot-poured sealants, the cold-poured materials, and the preformed seals. The hot-poured materials include tars, asphalts, and rubberized asphalts. The cold-poured materials include solvent-type asphalts, emulsions, and the 1- and 2-component elastomers. The preformed materials include the extruded shapes, such as the neoprene seal, the foams, and the presealed joints.

One of the objectives of this program has been to report the experience of the various State and Government authorities with the various classes of sealants. It is rather

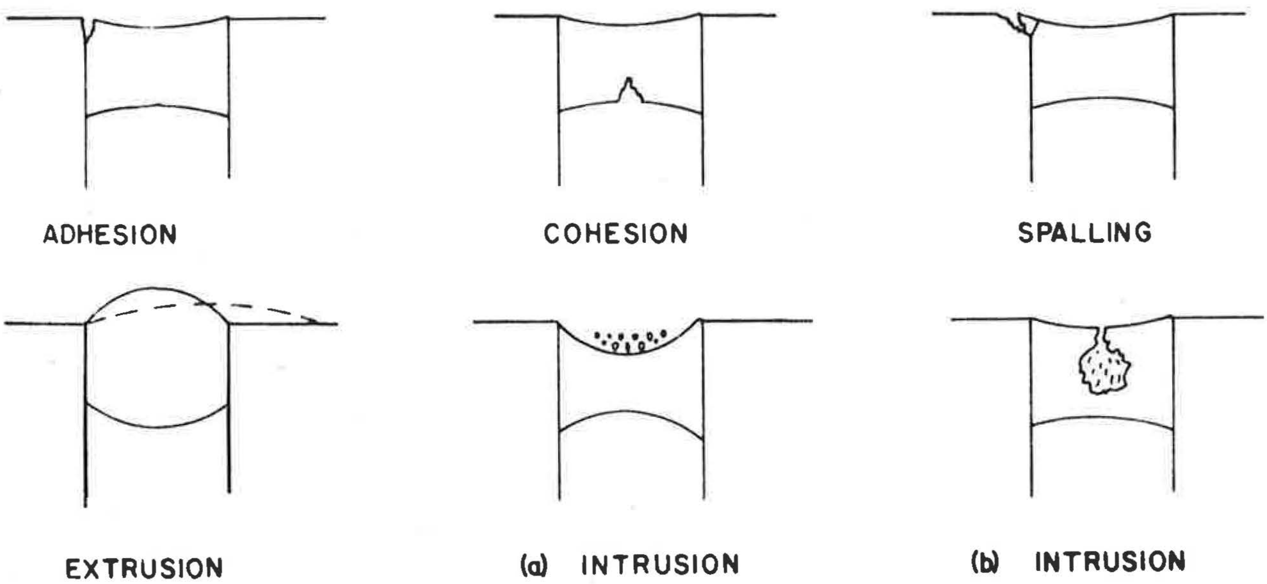

Figure 14. Types of joint failures.

Figure 15. A typical adhesive failure.

hazardous to form conclusions about materials which are used under widely varying conditions of temperature and slab design. It is also true that bad news travels fast, and the highway engineer in many cases remembers the failures more clearly than the successful installations. Moreover, even within a given State, widely divergent opinions may be heard concerning various materials. Whereas some States have discontinued the use of specific sealants, there are instances where each of the several types of sealants has performed satisfactorily. Producers of sealant materials, on the other hand, keep a rather careful record of successful installations and tend to explain away the failures. However, it should be noted that the producers in general look for causes of failure much more thoroughly than do the consumers, and in many cases their complaints and their explanations of failures are valid.

Among the hot-poured sealants, the tars and unmodified asphalts have largely faded from the picture to be replaced by the rubberized asphalts. The straight tars and asphalts, however, are still very widely used for crack sealing. The rubberized asphalt when first introduced contained as much as 25 to 30 percent rubber. However, competition has tended to downgrade this material, so that some of the current sealants contain very minor percentages of rubber. Sixty-eight percent of the States permit the use of this type of sealant, and it is still to a certain extent regarded as the industry standard. The rubber-asphalt sealants, if properly formulated, maintain a good bond to the joint wall even during cold-weather extension. Many of the so-called failures of this type of sealant can be traced to poor joint design and poor application. The rubber-asphalt sealant must be placed in a clean joint which has the proper shape factor. The material must be heated uniformly in a jacketed heater so that portions of the material are not overheated. Overheating of the sealant is probably the most common abuse of this type of material. This product deteriorates rapidly at sustained temperatures over 460° F. Reheating of leftover material is also a poor practice because this heat cycling tends to break down the sealant.

The cold-applied, rubber-asphalt compounds are materials that set up by solvent evaporation. They are readily pumpable at room temperature, but the solvent release causes a loss in volume; therefore, failures are common even in properly designed and applied installations. Only 16 percent of the States still permit the use of this type of sealant, and the number is decreasing. Very few of the highway engineers interviewed expressed any interest in this class of sealants.

The 2-component elastomeric- or polymer-type sealant is probably the most controversial sealant on the market today. This sealant consists of a base polymer and a curing agent which when thoroughly mixed cure into a tough, rubbery sealant at room temperature. Polysulfide sealants were the first polymeric sealants to be used in highway work. After a few years they were followed by the urethanes. Other elastomers, such as the polymercaptans and silicones, are currently undergoing laboratory investigation.

The polysulfide sealant, in addition to the base polymer and curing agent, contains some fillers and in some cases a plasticizing agent. The fillers and plasticizers can be added to either component, and the material can be either hand- or machine-mixed. When modified with coal tar, the polysulfide meets Federal Specification SS-S-00200c. The polysulfide sealants have had a stormy history in highway work. When first introduced in the 1950's, they looked like the most promising development in many years and were adopted by several States. Unfortunately, many of the early sealants were formulated by people with little highway experience and the polysulfide sealants were greatly oversold. Many of the early installations failed in the first 2 winters and gave all polysulfide sealants a bad name. Sixteen percent of the States have rejected polysulfides and currently only 10 percent of the States permit their use. However, research and development have not stopped, and some of the newer polysulfide sealants designed specifically for highway work look excellent. Several test cores cut through the joints of airfield pavements, including sections of the polysulfide sealant, showed a slightly crazed surface, but the main body of the sealant was still resilient and maintaining bond after 5 yr. Several manufacturers report examples of polysulfide sealant functioning well, especially in longitudinal joints, for over 5 yr.

The developers of urethanes, by entering the market somewhat later than the polysulfides, were able to profit by the mistakes made earlier. Whereas most of the urethanes in the New York State sealant test performed poorly and failed in the first 2 winters, there are several urethane installations which look good after 4 yr of service.

One major difference in behavior between the polysulfides and the urethanes is that, within rather broad limits, the polysulfides exhibit a stress relaxation whereas the urethanes do not. Stress relaxation is to a large extent controllable, and the question that remains to be answered is whether the stress relaxation should be designed out of the sealant material. The annual movement of a joint is such that a sealant material is held in an extended position for long periods of time. The fully elastic, nonrelaxing sealant will return to its original shape after long periods of extension, which, of course, is desirable. However, this material remains under stress throughout the winter, and any spalling of the joint will probably result in a fairly large failure. The relaxing sealant does not return to its original shape after long periods of stress, but, because it has relaxed into an equilibrium condition in its new shape, it is probably more resistant to puncture and tear propagation.

All of the pourable-type sealants should be placed in clean, properly designed joints. It is generally advisable to prime the joint faces to obtain maximum adhesion. The optimum cross-sectional shape for a liquid sealant is a width-to-depth ratio of 2 to 1. The sealant material should be bonded to the joint walls but not to the bottom of the joint. Normal practice is to place a strip of plastic foam in the bottom of the joint opening, leaving the opening above the foam in the proper width-to-depth ratio. The top surface of the foam filler is then covered with a plastic tape to prevent formation of a bond to the bottom of the joint. The sealant material is then placed in the joint. This complete sequence of operations is shown in Figures 16 through 19.

At the present time, no manufacturer recommends the use of a poured-type sealant in joints that will be extended more than 50 percent. The joint will move approximately 0.1 in. for each 30° F. (for 60-ft joint spacings). If the temperature differential is 90°, the joint will open 0.3 in. But if the initial joint width is ⅜ in., these conditions place the sealant under an 80-percent strain. Thus, for the sealant to perform satisfactorily, the ⅜-in. joint should be used with a shorter spacing. It is interesting to note that virtually all of the States which have discontinued the use of elastomeric sealants use a joint spacing of 60 ft or greater.

The overall trend in materials is definitely toward the Neoprene compression seal at this time. Ten percent of the States currently use this type of seal, several have it under test, and almost all of the States indicate an interest in this material. It is interesting to note, however, that only 17 percent of the State representatives interviewed felt that this material was the final solution to the sealing problem.

The preformed seal requires smooth, uniform joint walls to function properly. It does a good job of repelling incompressibles, but its watertightness is still questionable. Repairs are still quite costly to make, although new techniques are being developed. In resealing work, spalled areas must be repaired and joint interfaces rebuilt so that the seal can function. This makes resealing work quite expensive. The chief difficulty with the preformed seal is the stretching of the material during installation. Stretching the seal causes it to neck down and slip into the joint easily. This results in a reduced cross section which does not have the desired performance characteristics. Another difficulty with the compression seal is related to joint forming. Once a series of joints has been formed (or sawed), it is usually found that some of the joints have cracked through and others have not, so that the joint size is not uniform at the time of installation. It is also true, and this affects all sealants, that pavement slabs do not move uniformly; one joint may not crack, or if it has cracked it may subsequently freeze, so that the adjacent joints have to take up all the movement. The presealed joint looks good in theory, but none of the test installations are old enough to allow reports of any significant experience.

SPECIFICATIONS AND TESTS

The ultimate objective of a sealant-testing program is to develop a testing sequence that will reasonably predict field performance. This testing sequence should account for all aspects of pavement-joint behavior and environment, including heat, salt, water, ice, thermal expansion, curl, vertical deflection, and fatigue. At the present time, tests are not available to check all these variables and consequently the laboratory is used basically for screening before sealant materials are tested in the field. Field tests will be required, at least for several years, until a definitive laboratory sequence corroborated by field results can be established.

It is important to note that the bond test is apparently the backbone test of most specifications. In some of the specifications, the bond test cycle consists of extension and recovery; in others the cycle is extension and recompression to the original width. A more realistic test cycle would include both tension and compression, because contraction joints sealed at the ideal time are subjected to extension and recompression to the original width. However, in resealing work it is quite probable that the joint will be subjected to both extension and compression. None of the current specifications includes tests for shear, such as is encountered in vertical joint deflection, and none accounts for skewed joints or incremental movement. The effects of stress relaxation or compression set are not fully considered with the poured sealants.

The size and shape of test specimens require further study. At this time most specifications require the use of the ASA specimen, which is ½ in. by ½ in. by 2 in. Some testing facilities feel that this specimen size is not realistic and consequently use a longer specimen.

The bond test as currently used does not give a definitive measure of adhesive strength. A peel-adhesion test is used for development work, but is not required by any of the specifications which are applicable to highway work.

CRACK SEALING IN PAVEMENTS AND OVERLAYS

The bituminous pavement presents its own set of sealing problems. There are 2 major causes or types of cracks in bituminous pavement. One is the reflection crack which occurs through a bituminous overlay that has been placed on a rigid pavement base. This is a fairly regular crack pattern which corresponds to the joint and crack spacing in the pavement underneath. The other type of crack pattern is a random one which may be formed by thermal changes, frost heave, subgrade settlement, or any combination of these factors. These 2 types of cracking require entirely separate solutions. The reflection crack problem has been tackled from many aspects. Rather than attempting to seal the reflection crack, the emphasis has been on preventing its occurrence. This has been done in a number of ways, most of which involve bridging the crack underneath or placing reinforcement in the bituminous overlay. So far,

Figure 16. Elastomeric sealant installation; priming the joint.

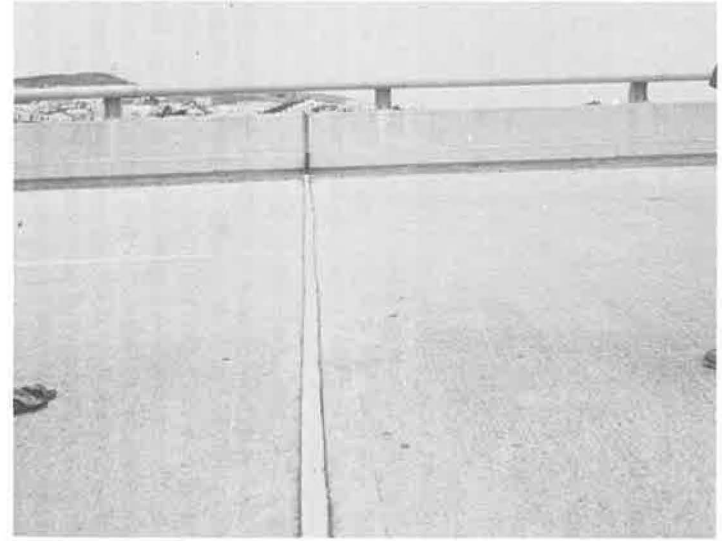

Figure 17. Elastomeric sealant installation; foam back-up material in place.

Figure 18. Elastomeric sealant installation; applying the bond-breaker tape.

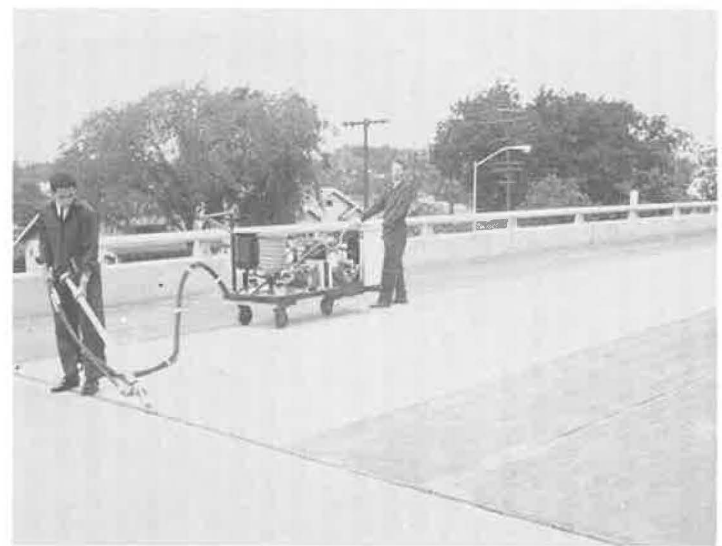

Figure 19. Elastomeric sealant installation; placing the sealant.

Figure 20. Crack repair in a rigid pavement.

none of these efforts has been entirely successful, and the recommendation of the Asphalt Institute is that the only way to prevent reflection cracking is simply to make the asphaltic overlay thick enough so that this overlay can accommodate and absorb the movements in the rigid pavement underneath.

Random cracking, as the name implies, shows no definite pattern. The cracks may be longitudinal, transverse, diagonal, or area-wide (which is called map cracking). The problem of sealing these cracks is perhaps even more formidable than that of sealing the cracks in rigid pavements. The cracks in bituminous pavements have no joint interface to which a preformed gasket could be attached. There is no real bond surface to which cold-poured elastimeric-type sealant could adhere; also, there is the problem of compatibility between any of the sealant materials and the asphalt-pavement material. Consequently, the sealing of the cracks in asphalt pavements has consisted largely of filling these cracks with some sort of bituminous filler. Hot-poured rubber asphalts and cold-poured, solvent-type asphaltics have been used, and in some cases the cracks are dusted with a fine sand in order to fill up the voids. There is at present no real accepted theory as to the proper sealing of cracks in bituminous pavement. In some instances, cracks in the bituminous pavement are routed with a small routing tool in the attempt to furnish truly vertical joint interfaces to which a sealant material can adhere. In other cases, the joints are simply poured full of some asphaltic material.

The sealing of area-wide cracking has been accomplished with some degree of success by the use of slurry seals or of coatings of various types. These seal coats are applied by spray, broom, or squeegee and are generally surfaced with a fine aggregate to provide skid resistance. Slurry-seal coatings are not generally recommended for portland cement concrete pavements.

Some structural repairs of rigid concrete pavements and bridge decks have been made with epoxy or epoxy-polysulfide combinations. Test installations look promising, but experience is scarce. Figure 20 shows a repair of this type.

COSTS

Costs of sealant installations vary widely from State to State. Bid prices cover a wide range, and in many cases they are a part of the total contract price for pavement.

New work figures are hard to ascertain because such items as joint sawing and cleaning may or may not be included in the bid price for joint sealing. The cost figures given in Table 4 include sawing, cleaning, and, where necessary, priming the joint. Foam backup material and bond-breaker tape are also included. The costs of resealing joints, as given in Table 4, include $0.07 per foot for joint cleaning. All the cost figures used were obtained from State highway departments, producers, and contractors.

As additional performance information becomes available, a statistical analysis can be made of cost-versus-performance data for each of the various materials. On the basis of limited evidence, the Neoprene seals appear quite high in first cost, but compare very favorably on a 5-yr performance basis.

CHAPTER FOUR

RECOMMENDED RESEARCH

A recommended research program for joint and crack sealing is by its nature a many faceted program. The problems of joint and crack sealing must be separated, studies of pavements should be made, and materials should be further investigated.

Because of the broad range of topics to be covered and the backup work in field studies which are necessary for correlation, it is not deemed advisable to recommend a large all-encompassing program which could be let in one contract. Therefore, the problem has been divided into separate areas that indicate the questions to be answered by the research within each area. Some grouping of these areas may be done, if desired, in order to provide fewer, but larger contracts.

PAVEMENT MOVEMENT

Many studies have been made of gross pavement movements in various areas of the country. What remains to be done is to round out the studies that have been made in order to cover all the variables of climate, as well as subbase type, load-transfer system, and joint spacing. What is now needed is a detailed study, possibly by electronic instrumentation, of sufficient pavements to ascertain whether incremental movement is prevalent and to determine its characteristics. Incremental or "slip-stick" pavement movement can be caused by binding of the load-transfer device or by the influence of subgrade and shoulder friction. The proposed instrumentation should include pavements with several types of shoulders, subgrades and load-transfer systems in order to isolate these variables. This instrumentation should also show the effects of wheel load and curl on vertical joint movement.

The pavement-movement studies should be conducted in at least 4 geographic areas, preferably with different joint spacings and load-transfer systems. Some information could be obtained from studies of existing pavements. The bulk of this research, however, would be best conducted in coordination with new pavement construction. This would permit more complete instrumentation and control and would provide the full history of the pavement movement. These studies should be made by, or in close cooperation with, an operating agency such as a State highway department or turnpike authority which has pavements under its jurisdiction.

SKEWED JOINTS

The study of skewed joints could be made in one location. It should be a laboratory investigation verified by field testing. The study should deal primarily with the effects of skew angle on the behavior of sealant materials. The bulk-type sealants in this situation are subjected to a combination of tension and shear. The preformed seal may have a tendency to "walk" out of the joint or to bunch up when subjected to repeated stress cycling.

Field correlation for this project would be difficult to obtain on existing highway pavements. Most available skewed joints are located at structures and some data could be obtained from this source for a wide variation in skew angle. A full investigation of this problem should be coordinated with new highway construction in which a range of skew angle sections could be constructed along with suitable control sections.

PREFORMED SEALS

One research program on preformed seals, currently being conducted by the New Jersey State Highway Department, involves the investigation of the watertightness of compression seals. However, this program is oriented toward bridge joints and is using larger sections than would be normally used in paving work.

A study of the shape, cross-sectional configuration, and wall thickness of compression seals might logically be considered as development work to be undertaken by the producers of sealant materials. However, the problem is complicated by patents of certain cross sections. Consequently, other producers must attempt alternate shapes and web configurations. It would be helpful to have an impartial investigation of the efficiency of the various shapes.

Competition has in many cases downgraded good materials. The material currently being used for compression seals has a good service record. However, the opinion is being heard among some producers that material costs are too high and that preformed seals can and should be made of cheaper materials.

The study of preformed seals should be undertaken by one agency. A laboratory investigation backed up by appropriate field tests would be required. The following aspects should be included:

1. Development of a practical flex-fatigue test.
2. An investigation of the watertightness of the seal.
3. An investigation of shape, wall thickness, and web configuration.
4. Development of a series of physical-chemical tests to keep competition from downgrading the raw material.

This last requirement is quite demanding because the tests would not limit producers to one source or one material. The test series must not stifle technological progress. Newer, cheaper materials must be permitted if they will perform satisfactorily.

ELASTOMERIC SEALANTS

The polymeric-type sealants, because they are involved in so many other fields besides highways, have probably been the subject of more research and development work than the other sealant types. However, much of this work was aimed at other applications which are not directly applicable to the highway field.

The program outlined could be undertaken by one research group. Although at first glance it may appear so, the object of this program is not to do the producer's development work for him. The program should include only those sealants now in use, not experimental types. In addition, the program should have a twofold objective, as follows:

1. Determination of the cause of failure of existing sealant materials.

2. Development of meaningful methods for evaluating new materials as they are introduced.

The research team would hopefully consist of an engineer experienced in sealant work and pavement behavior working in cooperation with a chemist or chemical engineer. Their investigation should include the following aspects:

1. Adhesion study. Most failures of polymer-type sealants are reported to be adhesion failures, yet there is no satisfactory measure of this property. The bond-extension test currently used is largely unsatisfactory as a measure of adhesion. The test developed might be either a tensile-adhesion test or an improved peel-adhesion test.

2. Work hardening investigation. Many sealants, when they fail, have hardened considerably. This could be a result of weathering; continuation of cure; or a working of the joint, somewhat analogous to the strain hardening of metals.

3. Fatigue study. This study is related to the high-frequency, low-amplitude vertical joint movement under the action of traffic.

4. Determination of the optimum force-elongation-adhesion relationships. Knowledge of the ultimate elongation capacity of a sealant material is, of itself, of little value. The importance lies in the amount of force necessary to produce a given elongation, and the relationship of this force to the adhesive strength of the sealant and the tensile strength of the concrete-joint interface. The testing rate, the rate and type of joint movement, and the stress-relaxation characteristics of the sealant are intimately involved in this investigation. The statement is often made that certain high-modulus elastomeric sealants cause spalling by pulling the concrete apart. During the pavement correlation studies, an investigation of sealed joints should be conducted to determine whether the type of sealant being used has any effect on the spalling of joints.

This study should also include consideration of the time of sealing as it relates to sealant behavior. The time of year in which a pavement is sealed will, in large measure, determine the limits of the tension-compression cycle to which the material is subjected.

5. Development of a rapid quality-control check test. This test should be a laboratory sampling to determine whether the material at the job site meets the manufacturer's original quality-control requirements. This test would be a measure of the shelf life and stability of the product. Inherent in this investigation might be a study of the desirability of requiring the manufacturers to use something more specific than an average molecular weight basis for their quality-control work.

HOT-POURED RUBBER ASPHALTS

The hot-poured sealants have been the most abused, but paradoxically the most used of any sealant type. Compared with the other sealant types, they have had relatively little research time and money spent on their development. The research program suggested should be conducted by a single research agency. The research team should include an engineer familiar with the requirements of the joint-sealing problem. This engineer should also have some background in the behavior of asphalts and flexible pavements, because much of the information gained will also be relevant to the crack-sealing problem. The research team should also include a chemist or chemical engineer. The following specific topics should be included in the investigation:

1. A measurement of resilience. This study would include research on resistance to penetration by incompressibles and resistance to abrasion and an investigation of the creep and stress relaxation of these materials.

2. Adhesion study. This should be directed towards both concrete and asphalt substrates. This material might be used for sealing concrete joints and cracks, for sealing cracks in bituminous pavements, or for sealing the longitudinal shoulder joint where bituminous paved shoulders are used.

3. Optimum rubber content. The change in rubber content is believed to be one of the causes of the downgrading of this type of sealant. This investigation should include a study of ground-versus-reclaimed rubber, the mesh size of rubber, the temperature relationships, and the possible inclusion of elastomeric compounds.

4. Optimum force-elongation relationship. The study should be of the same type as that recommended for the elastomers. (See item 4 under Elastomeric Sealants.)

CRACK SEALING

There has been some research work done on crack formation in relation to heave, settlement, and the effects of temperature, and a great deal of work on the reflection cracking of overlays. However, at present there is no accepted theory behind crack-sealing practices. The predominant philosophy at this time is simply to pour something in the joint.

Research on crack sealing might better be undertaken separately from joint-sealing work. This project need not be subdivided. It can feasibly be undertaken in a single contract. This research should evaluate past work on reflection cracking and attempt to provide a feasible method of controlling or sealing the reflection cracks. In addition to the reflection-cracking problem, this research should seek to answer the following questions:

1. Is the crack-sealing process necessarily a stop-gap operation, or could the pavement be welded into a structural unit? This question probably needs separate answers

for rigid and flexible pavements. Some of the crack-repair materials for rigid pavements look promising in this regard.

2. After the cracks are sealed, do the same cracks reopen with cycling or do new cracks form?

3. Should the cracks be routed to provide a uniform wall for sealant adhesion?

4. Should the cracks be poured full or should an attempt be made to employ a shape factor, such as that used with elastomeric joint sealants?

5. Are any of the existing sealing materials able to maintain bond to asphalt pavements under cyclic crack movement?

EDUCATION

An educational program is not, strictly speaking, recommended research, but it is possibly the most significant recommendation to be made by this report.

The successful installation of a joint sealant requires the efforts of many different groups; i.e. manufacturers, designers, test laboratory personnel, and contractors. Communication between these groups is weak. The specification is a form of this communication, but few of the people really involved ever see a copy of the specifications. In order to improve communication, the following educational program should be instituted:

1. Pavement designers must be made aware of the demands on, and the capabilities of, the various sealing materials.

2. Inspectors should be acquainted with the requirements for proper field installation of the sealing materials used. The inspector should also know the exact extent of, and limitations on, his authority.

3. Specification writers should know material properties and the limits within which successful field applications can be obtained.

4. Maintenance personnel should know the field limitations of materials and should be schooled in the proper techniques of application.

5. Contractors should be invited to meet with the other groups mentioned, to be made aware of sealing problems.

6. Producers should be more fully informed of the conditions of pavement movement. It must be said in defense of the manufacturers that they, in general, produce to meet a given specification. At the present time this gives them very little information to work with.

These educational purposes will not be served by national white-collar-type meetings. A good handbook would be of value, but written material is not an effective communication technique for many of the people involved. This program must be at the grass-roots level and designed to reach the really working people. Interdepartmental seminars within the State organizations would be helpful. Although the producers should be allowed to attend such sessions, they should not dominate the meetings. Contractors should also be invited to participate.

A program of education would establish better channels of communication as well as a feedback between the various groups involved. When combined with the results of the program of research proposed herein, effective joint sealing should become a practical reality.

APPENDIX A

ORGANIZATIONS CONTACTED

A broad cross section of highway departments, agencies, associations, and manufacturers was contacted during the course of the project. The following lists show those organizations which were investigated in depth by a personal interview with key personnel. These discussions provided detailed information beyond that obtained by questionnaires and correspondence.

STATE HIGHWAY DEPARTMENTS

California	Massachusetts	Ohio
Connecticut	Michigan	Tennessee
Florida	Minnesota	Virginia
Illinois	New Jersey	Washington
Kentucky	New York	Wisconsin
Maine	North Dakota	

AGENCIES AND ASSOCIATIONS

Adhesive and Sealant Council
American Association of State Highway Officials
American Concrete Institute
American Road Builders' Association
American Society for Testing and Materials (ASTM)
Asphalt Institute
Canadian Research Council
Federal Aviation Authority
Highway Research Board
Portland Cement Association
Society of the Plastics Industry
U. S. Air Force
U. S. Army Corps of Engineers
  Ohio River Laboratories
  Waterways Experiment Station
U. S. Bureau of Public Roads

U. S. Bureau of Reclamation
U. S. Bureau of Standards
U. S. Navy, Bureau of Yards and Docks (Now the Naval Engineering Facilities Command)

UNIVERSITIES

Georgia Institute of Technology
Massachusetts Institute of Technology
Rensselaer Polytechnic Institute
University of Connecticut
University of Kentucky
University of Maryland

INDUSTRIAL ORGANIZATIONS

Acme Highway Products Co.
Allied Materials Corp.
Diamond Alkali Co.
D. S. Brown Co.
E. I. duPont de Nemours, Inc.
Flintkote Corp.
Furane Plastics, Inc.
Gibson Homans Co.
Grace Construction Materials
H. S. Peterson Co.
Presstite Division of Interchemical Co.
Products Research and Chemical Co.
Pyles Industries, Inc.
Sika Chemical Co.
Thiokol Chemical Co.
Toch Bros. Co.
Union Carbide (Silicone Div.)
U. S. Rubber Reclaiming Co.
Wyandotte Chemical Co.

APPENDIX B

BIBLIOGRAPHY

This bibliography contains references related to the areas studied. Selected references are annotated. In general, those references whose value diminishes more rapidly with respect to time and those whose title is amply descriptive are not annotated. To indicate the specific area of the study, the items are classified as follows:

I. SEALANT MATERIALS
- A. General
- B. Theoretical and Laboratory Evaluation
- C. Chemical and Thermal Resistivity

II. JOINT AND CRACK SEALING
- A. General
- B. Joint-Forming Procedures
- C. Field Tests
- D. Slurry Seals and Seal Coatings

III. PAVEMENT DESIGN AND BEHAVIOR
- A. General
- B. Thermal and Moisture Effects
- C. Reflection Cracking

Items are not listed under more than one heading, and the classification of certain items is, by necessity, somewhat arbitrary. Because of the close interrelationships of the areas, it may be necessary to consult more than one group to locate the specific references desired.

To assist in interpreting references, the following code indication is employed at the end of each listing:

(1) Specific interest
(2) General interest
(3) Related field

(a) Long time value
(b) Intermediate time value
(c) Short time value

I. SEALANT MATERIALS

IA. GENERAL

1. ACI COMMITTEE 403, "Guide for Use of Epoxy Compounds with Concrete." *Jour. Am. Conc. Inst.*, No. 9 pp. 1121-1142 (Sept. 1962); *Hwy. Res. Abst.*, Vol. 33, No. 1, p. 19 (May 1963). (2)(b)

   The use of epoxies for crack and joint sealing is included. Methods of preparation, application, testing, and handling are discussed.

2. "A New Joint Sealing Compound." *Roads and Road Constr.* (London), Vol. 38, No. 446, p. 44 (Feb. 1960); *Hwy. Res. Abst.*, Vol. 30, No. 5, p. 28 (May 1960). (1)(c)

   "Polycast," a 2-component joint sealing compound, is described.

3. "Austrialian Research on Materials and Construction." *Australian Civil Eng. and Constr.*, Vol. 3, No. 4, pp. 36-37 (1962). (2)(b)

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12. DREHER, D., "A Structural Approach to Sealing Joints in Concrete." *Hwy. Res. Record No. 80*, pp. 57-73 (1965). (1)(a)

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30. "Plastics for Road Surfacing." *World Const.,* Vol. 18, No. 6, pp. 50-52 (June 1965). *Hwy. Res. Abst.,* Vol. 35, No. 11, p. 11 (Nov. 1965). (3)(c)

The use of Vestopal as a protective material for road surfaces and for patching damaged concrete surfaces is described.

31. "Polysulfides Serve the City."*American City,* Vol. 75, No. 1, pp. 84-86 (Jan. 1960). (1)(c)

32. REEGEN, S. L., "Peel Strength of Polyurethanes from Oxypropylene Polyols: I. Effect of Polyol Structure and Fillers." *Jour. Appl. Polymer Sci.,* Vol. 9, No. 1, pp. 279-294 (1965). (3)(b)

Application was made to bond between sealant and pavement.

33. Road Research Lab., "Filling and Sealing Materials for Joints in Concrete Roads." *Road Note No. 7,* 2nd ed., London, (1955). (1)(a)

34. Road Research Lab., "Road Research 1962." London (1963). (3)(c)

This report contains a section on joint-sealing materials.

35. "Rubber Finds Favor in Road Engineering." *Australian Civil Eng. and Constr.,* Vol. 2, No. 7, pp. 45-48 (1961). (3)(c)

36. "Rubber Jointing for Road Repairs." *Civil Eng. and Pub. Works Rev.* (London), Vol. 60, No. 702, p. 51 (1965). (1)(c)

The use of Neoprene for repairing cracks in Great Britain is described.

37. "Rubber Joints Seal for Road Cracks—Rapid Repair Method." *Contract Jour.,* Vol. 202, No. 4459, p. 823 (1964). (1)(c)

38. "Sealing Bridge Expansion Joints." *Civil Eng. and Pub. Works Rev.* (London), Vol. 58, No. 3, p. 465 (1963) (1)(c)

The use of Neoprene in Sweden is presented.

39. "Sealing Joints in Concrete Roads." *Surveyor* (British), Vol. 61, No. 3164, p. 678 (Oct. 1952). *Hwy. Res. Abst.,* Vol. 23, No. 1, p. 25 (Jan. 1953). (1)(c)

This article discusses the use of cane fiberboard impregnated with a bituminous compound and glass wool used with a rubber-bitumen compound.

40. SHINOZUKA, M., and FREUDENTHAL, A. M., "Strain Energy Functions for Filled Elastomers." *Jour. Appl. Polymer Sci.,* Vol. 9, No. 7, pp. 2565-2579 (1965). (3)(b)

41. "Stiff Compound Reseals Steep Channel Lining." *Constr. Equip.,* Vol. 11, No. 6, p. 43 (June 1955). (3)(c)

42. SUSKIND, S. P., "Polyurethane Latex." *Jour. Appl. Polymer Sci.,* Vol. 9, No. 7, pp. 2451-2458 (1965). (3)(b)

43. "The Filling of Joints in Concrete Pavements." *Strade,* Vol. 43, No. 3, pp. 174-180 (1963). (In Italian.) (1)(c)

The use of sponge rubber lightly treated with bituminous binder is presented.

44. "The Newark By-Pass—Developments in Concrete Carriageway Construction." *Roads and Road Constr.,* Vol. 42, No. 499, pp. 214-220 (1964). (1)(c)

This paper describes a new joint using temporary fiberboard and polystyrene filler.

45. VAN DER WAL, C. W., BREE, H. W., and SCHWARZL, F. R., "Mechanical Properties of Highly Filled Elastomers: II. Relationships Between Filler Characteristics, Thermal Expansion, and Bulk Moduli." *Jour. Appl. Polymer Sci.,* Vol. 9, No. 6, pp. 2143-2166 (1965). (3)(a)

The material used was a polyurethane rubber filled with various amounts of sodium chloride.

46. VANDERFLIERT, C., "Joint Filling for Cement Concrete Roads." *Wegen,* Vol. 29, No. 5, pp. 124-128 (May 1955). (In Dutch with English summary.) (1)(b)

47. "Vinyl Strip Seals Concrete." *Modern Plastics,* Vol. 29, No. 10, p. 79 (June 1952). (1)(c)

48. WORSON, L. "Plastic Insert Forms Contraction Joint, Seals Cracks, Ties Slabs. "*Southwest Builder and Contr.,* Vol. 133, No. 15, pp. 118-121 (April 10, 1959). *Hwy. Res. Abst.,* Vol. 29, No. 6, pp. 11-12 (June 1959). (1)(c)

"Constop" is a polyvinyl chloride plastic element with central bulb and wings and stops to the wings to provide ties. It is inserted into the concrete immediately after vibration and before finishing. It consists of a weakened-plane forming element and a waterstop element.

49. WORSON, L., "Plastic Joint Inserts after 33 Months of Service." *Southwest Builder and Contr.,* Vol. 137, No. 15, pp. 98, 100 (Apr. 14, 1961). *Hwy. Res. Abst.,* Vol. 31, No. 6, pp. 18-19 (June 1961). (1)(c)

An evaluation is given and modifications to the sealing device (previous entry) are described.

IB. THEORETICAL AND LABORATORY EVALUATION

1. AASHO, "Standard Specifications for Highway Materials and Methods of Testing. Part II, Methods of Sampling and Testing," Am. Assoc. of State Hwy. Officials, Wash., D.C. (1961). (2)(a)

2. BALLANTYNE, E. R., "Rheological Properties of Certain Joint-Sealing Compounds for Concrete Canal Linings."

Tech. Paper No. 2, Div. of Building Res., Commonwealth Sci. and Ind. Res. Org. (Melbourne), (1954). *Hwy. Res. Abst.,* Vol. 25, No. 5, p. 4 (May 1955). (1)(b)

The flow properties of 5 bituminous jointing compounds were determined in the laboratory by extrusion through tubes. Information on pressures, temperatures, and nozzle size was thus inferred.

3. CHANG, F. S. C., "Stress Relaxation and Hysteresis at Various Strain Rates." *Jour. Appl. Polymer Sci.,* Vol. 8, No. 1, pp. 37-52 (1964). (3)(b)

General theoretical article with possible applications to sealant materials.

4. COOK, J. P., "A Study of Polysulfide Sealants for Joints in Bridges." *Hwy. Res. Record No. 80,* pp. 11-35 (1965). (1)(a)

Polysulfide sealants are shown to be viscoelastic and to exhibit the interrelated phenomena of creep and stress relaxation. Curves are included for modulus of elasticity, for creep, and for stress relaxation with shape, Shore hardness and temperature as parameters. Sample solutions are shown for the stresses in sealants under various loading conditions including tension plus shear and compression plus shear. A stress-relaxation equation is derived and verified by photoelasticity.

5. COOK, J. P., "Effect of Specimen Length on Laboratory Behavior of Sealants." *Hwy. Res. Record No. 80,* pp. 74-78 (1965). Also in *Adhesives Age* (Nov. 1965). (1)(a)

The effect of specimen length is evaluated by comparing the stresses computed mathematically, the laboratory tests of neckdown during elongation, and a photoelastic analysis of stresses. Two-, 4-, and 6-in. specimens are evaluated and the larger specimens are recommended.

6. DABIN, J., "Testing Methods and Useful Characteristics of Joint Sealing Compounds for Concrete Surfacings." *Centre de Recherches Routiers, Rapport de Recherche* (Brussels), 54 pp. (1955). (In French.) *Road Abst.,* Vol. 23, No. 1, p. 12 (Jan. 1956). *Hwy. Res. Abst.,* Vol. 26, No. 8, p. 13 (Sept. 1956). (1)(a)

Research at the Belgian Research Center. The tests studied were: lateral and vertical flow, cone penetration, settlement of filler, resistance to vehicle fuels, cohesion and adhesion to concrete, and ring-and-ball softening point. The results of tests of 37 sealing compounds were tabulated. The most satisfactory tests were found to be: vertical flow, static load, impact penetration, filler settlement, resistance to fuel, and determination of cohesion and adhesion. Suggesions are included for standard methods of testing.

7. DREHER, D., "A Structural Approach to the Sealing of Joints in Concrete." *Hwy. Res. Record No. 80,* pp. 57-73 (1965). (1)(a)

A wide variety of preformed compression seals are analyzed as structural elements.

8. FARRIS, R. S., and BILLS, K. W. "Dilation of Granular Filled Elastomers Under High Rates of Strain." *Jour. Appl. Polymer Sci.,* Vol. 8, No. 1, pp. 25-35 (1964). (3)(b)

An interesting laboratory technique is presented.

9. HOROWITZ, E., and MANDEL, J., "Determination of Bitumen Content in Expansion Joint Fillers." *Mater. Res. and Standards,* Vol. 3, No. 9, pp. 723-725 (1963). *Hwy. Res. Abst.,* Vol. 34, No. 8, pp. 12-13 (Aug. 1964). (1)(b)

A Soxhlet extraction method is compared with the ASTM centrifuge method for the determination of bitumen content in expansion-joint filler made of bitumen and cellulose fiber, of cork, or of glass wool. The Soxhlet procedure requires less operator time and smaller amounts of solvent and makes it possible to analyze many samples concurrently with a minimum of attention.

10. JONSSON, P. O., "Testing of Concrete Pavements and Asphalt Compounds for Sealing of Joints." *Statens Provingsanstalt,* Meddelande (Stockholm), No. 107, 14 pp. (1951). (In Swedish and summary in English.) (1)(b)

11. JOHNS, H., "New Device Tests Contraction Joint Sealer." *ASTM Bull. No. 232,* pp. 67-68 (Sept. 1958). *Hwy. Res. Abst.,* Vol. 29, No. 3, p. 3 (March 1959). (1)(b)

12. KAPERNICK, J. W., "Equipment for Studying Pavement Joint Performance in the Laboratory." *Jour. Portland Cement Assoc. Res. and Dev. Lab.,* Vol. 5, No. 2, pp. 7-13 (1963). *Hwy Res. Abst.,* Vol. 33, No. 7, p. 6 (July 1963). (3)(b)

Equipment is described that permits the evaluation of the effect of the temperature variation, the subgrade support, and the magnitude and number of load applications on the action of transverse joints. Although the equipment was designed to study load-transfer devices, it could be used to study the behavior of sealed joints.

13. KUENNING, W. H., "Laboratory Tests of Sealers for Sawed Joints." *HRB Bull. No. 211,* pp. 1-12 (1959). (1)(a)

Tension and compression cycling tests were performed on a variety of sealing materials. The results showed that extensibility is not strictly an inherent property of the material, but is highly dependent on the relative dimensions of the cross section (shape factor). The conclusion is drawn that initial joint widths must be designed in relation to the sealant material, the joint spacing, and the climate.

14. MILES, D. O., KNOLLMAN, G. C., HAMAMOTO, A. S., and NORSTROM, G. C., "Mechanical Shear Relaxation Spectroscopy in Experimental Viscoelasticity." *Jour. Appl. Polymer Sci.,* Vol. 9, No. 6, pp. 2209-2225 (1965). (3)(b)

A possible laboratory test for sealant materials is described.

15. POTTS, J. C., "Some Observations on the Absorption of Moisture by Elastomeric Solid Propellant Binders." *Jour. Appl. Polymer Sci.,* Vol. 9, No. 5, pp. 1841-1852 (1965). (3)(b)

16. SCHUTZ, R. J., and VAN HAUTER, A. G., "New Concrete Joint Sealant Testing Machine." *ASTM Bull. No. 241,* pp. 42-44 (Oct. 1959). (1)(b)

A machine is described which was developed for the testing of joint-sealing materials. It is capable of performing the following functions: extension, compression, variable rates of load application, determination of the force required for extension and compression, determination of maximum extension, fatigue failure, and environmental testing.

17. SCHUTZ, R. J., "Shape Factor in Joint Design." *Civil Eng.*, Vol. 32, No. 10, pp. 32-36 (Oct. 1962). (1)(a)

The effect of the cross-sectional dimensions or "shape factor" on sealant materials is presented. A list of factors to consider in designing joints includes such items as: sealants change shape, not volume, with extension or compression; with a given sealant and given conditions, the shape factor of the joint will determine its performance; bond breakers should be employed at the bottom surface of all elastomeric sealants; because the force required to stretch the sealant increases as the temperature decreases, the lowest service temperature should be used as the basis for selecting the sealant; the hardness of the sealant to be chosen will be determined by service temperature, anticipated movement, and resistance to abrasion.

18. SMITH, G. W., "Measurement of Brittleness Temperature of Neoprene by Proton Magnetic Resonance: Effect of Plasticizers." *Jour. Appl. Polymer Sci.*, Vol. 4, No. 4, pp. 1553-1560 (1965). (3)(b)

Temperature ranges used were from 80° to 280°K.

19. TONS, E., and ROGGEVEEN, V. J., "Laboratory Testing of Materials for Sealing Cracks in Bituminous Concrete Pavements." *Hwy Res. Abst.*, Vol. 25, No. 8, pp. 19-31 (Sept. 1955). (1)(b)

Numerous sealants were studied to determine their effectiveness in sealing reflection cracks. Tests run included: bond-ductility, pour point, penetration, flow, volume change, tackiness, and age hardening. It was concluded that it would be difficult to develop a material that would perform adequately in the typical ⅛-in. crack. Some materials, however, give promise for use in ¼-in. cracks.

20. TONS, E., "Comparative Testing of Joint Sealers in Sixteen Laboratories." *HRB Bull. No. 211*, pp. 13-22 (1959). (1)(b)

Sixteen different testing laboratories were asked to participate in the evaluation of bond-ductility, of flow, and of penetration tests for joint-sealing compounds. Materials derived from one source were sent to all participants. The Federal Specification SS-R-406c procedure was used, emphasizing certain details for better control. Conclusions reached were: the bond-ductility test should be restudied to assure better reproducibility; the flow test is not accurate, but gives reasonably comparable results; and the penetration test appears to give relatively reproducible results.

21. TONS, E., "A Theoretical Approach to Design of a Road Joint Seal." *HRB Bull. No. 229*, pp. 20-53 (1959). (1)(a)

The results of a study are presented in which joint width, sealed depth, joint expansion, and sealer extensibility are correlated mathematically and experimentally. An approach to a practical joint-seal design procedure is given.

22. TONS, E., "Geometry of Simple Joint Seals Under Strain." *Build. Res. Inst. Rep. No. 1006*, pp. 40-49 (1962). (1)(b)

23. TONS, E., "Factors in Joint Seal Design." *Hwy. Res. Record No. 80*, pp. 49-56 (1965). (1)(b)

The problems of sealant elasticity, which places long-term stresses on the bond interface, versus stress relaxation, which may cause permanent shape deformation, are discussed. It is concluded that compression-type sealants show promise where large joint-width variations are expected. Poured-in-place, tension-compression sealants can be expected to perform well in cracks and in joints with small cyclic width variations.

24. TONS, E., "Materials and Geometry in Joint Seals." *Adhesives Age*, Vol. 8, No. 9, pp. 22-28 (1965). (1)(b)

25. YIN, T. P., and PARISER, R., "Dynamic Mechanical Properties of Several Elastomers and Their Potentialities in Vibration Control Applications." *Jour. Appl. Polymer Sci.*, Vol. 8, No. 5, pp. 2427-2433 (1964). (3)(b)

The possible extension to the behavior of Neoprenes under slab movement is presented.

26. ZISMAN, W. A., "Influence of Constitution on Adhesion." *Ind. and Eng. Chem.*, Vol. 55, No. 10, pp. 18-38 (1963). (3)(a)

A survey of the status of adhesion and bonding is made. This paper contains a 102-item bibliography.

IC. CHEMICAL AND THERMAL RESISTIVITY

1. "Airfield Apron Sealed Against Jet Fuel." *Roads and Streets*, Vol. 104, No. 7, p. 104 (1961). (1)(c)
Coal tar is used as a pavement sealer.

2. FRY, X. B., MATHEWS, M. J., and JOSEPH, A. H., "Performance of Rubberized-Tar Concrete Pavements on Airfield Facilities." U.S. Army Corps of Eng., Waterways Exper. Station, Vicksburg, Miss. *Misc. Paper 4-304*, pp. 1-10 (Feb. 1959). (1)(b)

This paper describes observations of the behavior of in-place, rubberized-tar concrete pavements at 14 Air Force bases. The effects of jet heat and blast, jet-fuel spillage, weathering and cracking were studied. Fuel spillage caused only insignificant damage and the pavements withstood jet blast very well.

3. HANSEN, R., "Fuel Spillage, Traffic, and Blast Testing of Maintenance Materials for Rubberized-Tar Concrete Airfield Pavements." U.S. Army Corps of Eng., Waterways Exper. Station, Vicksburg, Miss. *Tech. Rep. 3-493*, pp. 1-31 (Feb. 1959). (1)(b)

This report presents the results of field tests on all available (May 1957) maintenance materials for rubberized-tar concrete pavements. The purpose of this study was to observe the behavior of each of the available maintenance materials with reference to method and ease of application and quality of performance, and to evaluate the suitability of each material for use in maintenance of rubberized-tar, concrete airfield pavements.

4. "Joint Sealer Impervious to Jet Fuel and Blast." *Eng. News-Record*, Vol. 151, No. 23, pp. 106 and 108 (Dec. 3, 1953). (1)(c)

5. MCFADDEN, G., "The Effect of Jet Aircraft on Airport Pavements." *Trans. Am. Soc. of Civil Eng.*, Vol. 121, No. 2795, pp. 172-178 (1956). (1)(a)

Tests are described to determine the effect of jet blast and fuel spillage on bituminous concrete and portland cement concrete pavements. Measures to guard against such damage are given.

6. "Paving Joint Sealer Jet Blast Resistant." *Michigan Roads and Const.*, Vol. 50, No. 41, p. 12 (Oct. 8, 1953). *HRB Abst.*, Vol. 24, No. 2, p. 5 (Feb. 1954). (1)(c)

7. "Rubbery Paving Joint Fillers Have Increased Solvent Resistance." *Hwy. Builder*, Vol. 33, No. 9, pp. 23, 29 (Sept. 1954). *Hwy Res. Abst.*, Vol. 24, No. 10, pp. 12-13 (Nov. 1954). (1)(c)

   Describes a modified thermoplastic polyloid elastomer which may be made for hot or cold pouring, for extrusion, or for spread coatings.

8. "Evaluation of the Effect of Alkalies and Accelerated Extraction Tests." U.S. Army Corps of Eng., Waterways Exper. Station, Vicksburg, Miss., *Tech. Report 6-546, No. 2* (March 1961). (3)(b)

II. JOINT AND CRACK SEALING

IIA. GENERAL

1. "A Study of Standard Joints for IRI Motorways." *Autostrade Torino*, Vol. 5, No. 4, pp. 7-10 (1963). (In Italian.) (1)(c)

   An Italian expansion joint using metal parts is presented.

2. ACI Subcommittee III of Committee 325, "Structural Design Considerations for Pavement Joints." *Jour. Am. Conc. Inst.*, Vol. 53, No. 1, (July 1956). (2)(b)

   Considerations are presented for the structural design of joints in concrete pavements. A description, function, and classification of joints; assumptions and materials to be used; and details of joint design are included.

3. Anderson, A. A., "Expansion Joint Practice in Highway Construction." *Trans. Am. Soc. of Civil Eng.*, Vol. 114, pp. 1159-1176 (1949). (1)(a)

   The trend is toward the elimination of expansion joints. Information is taken from Michigan and Minnesota projects. Strain gage readings of compressive stresses measured in the field are given. For pavements built with properly spaced and maintained contraction joints, expansion joints may be eliminated, except for unusual conditions of construction.

4. Anderson, A. A., "Current Practice Questionnaire—Jointing, Fillers, Sealers and Equipment." *HRB Bull. No. 138*, pp. 11-24 (1956). (1)(b)

   The results of a 1965 questionnaire received from some 43 States and 5 other agencies are tabulated and summarized.

5. "Bearings and Expansion Joints in New Coventry Flyover." *Rubber Dev.* (British), Vol. 18, No. 3, pp. 103-104 (1965). (1)(c)

6. "Bonded Rubber Expansion Joint for Bridges." *Engineering* (British), Vol. 193, No. 5012, p. 620 (May 11, 1962). *Hwy. Res. Abst.*, Vol. 33, No. 1, pp. 10-11 (Jan. 1963). (1)(c)

   The use of a precompressed bonded-rubber bridge expansion joint is described.

7. Britton, H. B., "Bridge Joint Sealing—Its Materials and Mechanical Problems." *Hwy. Res. Record No. 80*, pp. 36-41 (1965). (1)(a)

   New York State's search for bridge joint sealants since 1952 is described. Specifications and procedures are recommended.

8. California Div. of Highways, "Study to Develop and Evaluate an Improved Bridge Deck Expansion Joint." Mater. and Res. Dept., 1964.

   The joint consists of dovetailed metal sections and a Neoprene apron.

9. Cook, J. P., "Effective Sealing of Expansion Joints in Highway Construction." *Am. Road Builder*, Vol. 41, No. 1, pp. 8-11 (Jan. 1964). (1)(c)

   Included in the paper are a discussion of the problem, a description of the various types of failures, and a description of current research and possible solutions.

10. Cook, J. P., "The Application of Sealants to Building Construction." *Proc. Polymer Conf. Series*, Wayne State Univ., June 1965. (3)(c)

11. Cook, J. P., "The Application of Sealants to Highway Construction." *Proc. Polymer Conf. Series*, Wayne State Univ., Detroit, Mich., June 1965. (1)(b)

    A general description of the problem is presented. Example computations of sealant strains are given both for temperature differentials and for deflections of bridge spans due to traffic loadings.

12. Cook, J. P., "Design Considerations for Sealing the Expansion Joint." *Building Res.*, July–Aug. 1966. (1)(c)

13. Crandel, J. S., et al., "Experience in Illinois with Joints in Concrete Pavements." *Bull. Series No. 365*, Eng. Exper. Station, Univ. of Illinois, Urbana, Ill., 258 pp. 1947.

14. Cryderman, S. F., and Weinbrauck, "Sealing Joint Between Concrete Slab and Bituminous Shoulder." *Pub. Works*, Vol. 95, No. 4, pp. 116-117 (1964). (1)(c)

15. Critchell, P. L., "Joints and Cracks in Concrete." *Contractors Record*, London, 232 pp., 1958. (2)(a)

16. Dews, N. A., "Some Aspects of Bridge Maintenance." *Highway and Bridge*, Vol. 32, No. 1566, pp. 8-10 and 22 (1964). (2)(c)

    Both cracks and joints are discussed.

17. Ewers, N., and Villaret, L., "The Joint Problem in Concrete Pavements." *Strasse* (Berlin), Vol. 4, No. 2, pp. 76-88 (1964). (In German.) (1)(c)

18. Ewers, N., and Villaret, L., "Experience with Various Types of Joint in Concrete Roads." *Strasse* (Berlin), Vol. 4, No. 4, pp. 195-204 (1964). (In German.) (1)(c)

19. Expansion Joint Inst., "Design Practices and Uses of Premoulded Joints in Concrete Pavements." Aurora, Ill. 23 p., 1957. (1)(a)

20. "Expansion Joints in Runnymede Bridge." *Civil Eng. and Pub. Works Rev.* (London), Vol. 57, No. 668, p. 355 (1962). (1)(c)

21. "Experience of Slip-Form Paving from Cromwell By-Pass Experiment." *Civil Eng. and Pub. Works Rev.* (London), Vol. 60, No. 711, pp. 1471-1473 (1965). (2)(c)

This paper discusses an experiment to develop joints for slip-form paving.

22. "Fast Deck Job—Pavers Rode Right Over Joints." *Roads and Streets,* Vol. 107, No. 3, pp. 104-114 (1964). (1)(c)

Owing to rush-job conditions, the contractor paved over expansion and finger joints. Rope was stuffed in expansion joints and finger joints were covered with wood.

23. Foster, C. R., Hudson, S. B., and Nelson, R. S., "Constructing Longitudinal Joints in Hot-Mix Asphalt Pavements." *Hwy. Res. Record No. 51,* pp. 124-136 (1964). (1)(a)

Presents results of density and tensile strength tests of samples cut from longitudinal joints in hot-mix asphaltic pavement. In semi-hot and cold joints, there is a low-density zone at the joint in the lane paved first and a high-density zone at the joint in the lane paved subsequently. These zones are not present in hot joints made with pavers operating in echelon. These low- and high-density zones may well be the basic problem in constructing durable longitudinal joints in asphaltic pavements.

24. Gartner, W., Jr., and Smith, "Problems Associated with Joints in Concrete Pavements." Div. of Mater., Res. and Training, Florida State Road Comm., Gainesville, Fla. (1965). (Presented at the 24th Ann. SASHO Conv., Raleigh, N.C., Nov. 7-10, 1965). (2)(b)

25. "State Highway Department Practices in Filling, Sealing, and Maintaining Joints in Concrete Pavements." Hwy. Res. Bd., Washington, D.C., 1950. (1)(b)

26. Holmes, B. M., "Sealing of Joints in Concrete Canal Linings, with Special Reference to the Kiowa Hydroelectric Project." *Tech. Paper No. 1,* Commonwealth Sci. and Ind. Res. Org. (Australian), 32 pp. (1954). (3)(b)

27. Intern. Union of Testing and Res. Labs. for Mater. and Structures, "Symposium on Bond and Crack Formation." *Proc. Tekniska Hogskolans Rotaprinttryckeri,* Stockholm, 1957. (Papers in English or French with summaries in both languages.) (2)(b)

28. Joint Sealers Mfg. Assoc., "Joint Sealing Manual; The Sealing of Joints and Cracks in Concrete and Bituminous Pavements." Oklahoma City, 18 pp., 1957. (1)(b)

29. "Joint Sealer Used in Colorado." *Pacific Road Builder and Eng. Rev.,* Vol. 86, No. 4, p. 59 (April 1956). (1)(c)

30. Kellam, B., and Loughborough, M. T., "Waterstops for Joints in Concrete." *Jour. Am. Conc. Inst.,* Vol. 30, No. 12, pp. 1269-1286 (June 1959). *Hwy. Res. Abst.,* Vol. 29, No. 9, p. 15 (Oct. 1959). (3)(b)

Six categories of waterstops are compared for watertightness. The flat corrugated and flexible metal types were found to be superior as compared with the dumb-bell and metal plate types.

31. Kirkham, R. H. H., "The Riding Quality of Concrete Roads." *Tech. Paper No. 60,* Road Res. Lab. (London), 1963. (3)(b)

The problem of pavement joints is included.

32. Kleinlogel, A., *Expansion Joints in Concrete and Reinforced Concrete Structures.* Uberard. aufl., (Berlin), Ernst, 272 pp., 1958. (2)(a)

33. Klemp, W., "New Joint Design for Complete Surfacings—A Contribution to Solving the Problem of Joints in Road Pavements." *Beton* (Dusseldorf), Vol. 12, No. 12, pp. 557-558 (1962). (In German with English summary.) (2)(b)

34. Laird, C. B., "New Developments in Pavement Jointing." *HRB Bull. No. 162,* pp. 8-12 (1957). (1)(b)

Michigan State Highway Department's developments in joints during the period 1940-1955.

35. Lee, L. D., "Sealing Contraction Joints and Cracks in Concrete Pavements." *Pub. Works,* Vol. 94, No. 7, pp. 103-104 (July 1963). (2)(c)

Current practices are reviewed.

36. Meshcheryakov, L. I., "The Use of Rubber Support Sections and Joints in Bridges." *Avtom. Dorogi,* Vol. 26, No. 3, pp. 17-19 (1963). (In Russian.) (1)(c)

37. Oehler, L. T., "Joints in Portland Cement Concrete Pavement." Res. Lab. Div., Michigan State Hwy. Dept., Lansing, Mich., 1963. (Paper prepared for 4th Ann. Hwy. Conf., Mich. College of Mining and Tech., Houghton, Mich., Oct. 3-4, 1963. (2)(b)

38. Persson, B. O. E., "Continuously Reinforced Concrete Pavement and Elastic Joints." *Svenska Vagforen Tidskr.,* Vol. 49, No. 10, pp. 422-426 (1962). (In Swedish with English summary.) (2)(b)

A brief summary of joint research in Sweden and other countries is presented.

39. Persson, B. O. E., "Experiments with Joints in Concrete on the Motorway at Ullana." *Svenska Vagforen Tidskr.,* Vol. 50, No. 9, pp. 379-384 (1963). (In Swedish with English summary.) (1)(c)

Serious spalling was caused by the loss of wood joint filler and by creep. Epoxies and other plastic and synthetic materials are now being tried, as well as rubber-bitumen and rubber-tar.

40. Ray, G. K., "Joint Construction in Concrete Pavements." *HRB Bull. No. 229,* pp. 11-19 (1959). (2)(a)

A general review of the types of joints and their design characteristics is presented and correct construction procedures are outlined and illustrated. Installation of dowels, of tiebars, and of expansion-joint fillers is explained.

41. "Repairing Cracked Concrete Road Slabs." *Road and Road Constr.* (London), Vol. 43, No. 505, p. 13 (1965). *Hwy. Res. Abstr.,* Vol. 35, No. 9, p. 1 (Sept. 1965). (1)(b)

A method of sealing longitudinal cracks developed by the Road Research Lab. is given. An extruded wedged-shaped Neoprene sponge with malleable wire run through its longitudinal holes is used. The seal strip is placed along a broken-out line along the crack and then the excavated area is filled with epoxy-resin/sand mortar.

42. Kyser, J. O., and Rice, C. E., "Restoration of Joint and Spall Failures on PCC Pavement." *Hwy. Res. Record No. 146*, pp. 28-33 (1966). (1)(b)

The work consisted of resawing the transverse joints, removing all adjacent unsound concrete, patching the spalled areas, and installing Neoprene compression seals. Small spalls were patched with epoxy resin, and larger areas were patched with air-entrained portland cement concrete.

43. Rosenthal, L. H., "Crack Sealing Program Protects Old Pavements." *Pub. Works*, Vol. 93, No. 6, pp. 108-110 (June 1962). (1)(c)

Joint- and crack-sealing program used in Portland, Oregon.

44. "Rubber Sealed Expansion Joints for New Reservoir." *Australian Civil Eng. and Constr.*, Vol. 6, No. 4, p. 41 (1965). (3)(c)

45. Scotti, A., "Problems of Intense Traffic Expansion Joints." *Strade e Traff.*, Vol. 11, No. 121, pp. 15-18 (1964). (In Italian.) (1)(b)

Lists criteria for, and illustrates 12 types of joints.

46. Steele, B. W., "Cracks in Concrete." *Proc. Am. Conc. Inst.*, Vol. 43, pp. 629-633 (1947). (3)(b)

47. Sternberg, F. E., and Creamer, W. M., "Cleaning and Resealing of Concrete Pavement Joints by Contract." *HRB Bull. No. 138*, pp. 1-10 (1956). (1)(b)

The resealing procedure employed by the Connecticut State Hwy. Dept. is described.

48. Swanberg, H. J., "Maintenance of Joints, Cracks, and Spalls." *Pub. Works*, Vol. 94, No. 10, pp. 104-106 (1963). (1)(b)

49. Teller, L. W., and Sutherland, E. C., "A Study of the Structural Action of Several Types of Transverse and Longitudinal Joint Designs." In *The Structural Design of Concrete Pavements*, Reprinted from *Pub. Roads*, Vol. 16, Nos. 8, 9, and 10, Vol. 17, Nos. 7 and 8, and Vol. 23, No. 8, pp. 67-114 (1935-42). (2)(a)

50. "The Construction of the London-South Wales Motorway M. 4." *Civil Eng. and Pub. Works Rev.* (London), Vol. 60, No. 703, pp. 219-235 (1965). (2)(c)

51. U.S. Army Corps. of Eng., "Investigation of Sawed Joints in Concrete Pavements." Rigid Pavement Lab., Ohio River Div. Labs., Mariemont, Ohio, 1954. (2)(a)

52. U.S. Army Corps of Eng., "Investigation of Methods of Preparing Horizontal Construction Joints in Concrete." *Tech. Rep. No. 6-518*, Waterways Experiment Station, Vicksburg, Miss., 1959. (2)(a)

53. Van Breemen, W., and Finney, E. A., "Design and Construction of Joints in Concrete Pavement Surfaces." *Proc. Am. Conc. Inst.*, Vol. 46, pp. 789-820 (1950).

54. Van Breemen, W., "Filling and Sealing of Joints and Cracks in Concrete Pavements." *HRB Bull. No. 78*, 38 pp. (1953). (1)(a)

This paper presents the various kinds of filling and sealing materials and their functions, capabilities, and limitations. Detailed information of joint movement is included.

55. Walsh, W. J., "Skewed Contraction Joints for Concrete Pavements." *Pub. Works*, Vol. 93, No. 3, p. 102 (Mar. 1962). (1)(b)

A brief review of the use of skewed joints is presented. The primary advantage gained is the reduction of load-transfer stresses. Colorado's use of a joint skewed 5 ft in 24 ft is described.

56. Watson, S. C., "Performance of a Compression Joint Seal." *Hwy. Res. Record No. 80*, pp. 79-100 (1965). (1)(a)

Typical joint failures are discussed and illustrated. The use of preformed, compartmented, polychloroprene, compression-joint seals is presented.

57. Worson, L., "Plastic Joint Inserts After 33 Months of Service." *Southwest Builder and Contr.* (Los Angeles), Vol. 137, No. 15, pp. 98 and 100 (Apr. 14, 1961). *Hwy. Res. Abst.*, Vol. 31, No. 6, pp. 18-19 (June 1961). (1)(c)

Experience with a vinyl plastic or butyl rubber weakened-plane contraction joint is presented.

IIB. JOINT-FORMING PROCEDURES

1. Arndt, W. J., "Kansas Experience with Concrete Saw for Cutting Contraction Joints in Concrete Pavement." *Proc. HRB*, Vol. 30, pp. 108-113 (1950). (1)(b)

2. "Depth Marker Inspects Sawed Joints." *Pub. Works*, Vol. 94, No. 7, p. 85 (July 1963). (1)(b)

A simple device is described that determines when joints have been sawed to the prescribed minimum depth. A large disk attached to a handle is rolled along the joint. When the joint is less than the prescribed depth, an inked wheel contacts the pavement surface.

3. Hardy, F. E., "Power Mower Cleans Expansion Joints." *American City*, Vol. 76, No. 3, p. 10 (1961). (1)(c)

4. Janowitz, R., "Some Do's and Don'ts of Concrete Sawing." *Roads and Streets*, Vol. 102, No. 6, pp. 78-80 and 82 (June 1959). (1)(b)

A discussion of equipment selection, equipment operation and maintenance, and blade selection.

5. Miller, E. M., "Joint Sawing Experience with Hard Aggregates." *Roads and Streets*, Vol. 106, No. 9, pp. 52 and 56 (Sept. 1963). (1)(b)

On the basis of the construction experience at Dulles International Airport, it was concluded that the presence of extremely hard aggregate does not preclude the use of sawed joints.

6. Monson, R., "Paver Attachment Cuts Diagonal Joints, Places Plastic Strips." *Contr. and Eng.*, Vol. 60, No. 9, pp. 36-41 (1963). *Hwy. Res. Abst.*, Vol. 33, No. 11, p. 13 (Nov. 1963). (1)(c)

Joints are formed by a vibrating knife that travels with the paving apparatus. Polyethylene strips are inserted directly in the green concrete. Joint sawing was completely eliminated.

7. PERENCHIO, W., "Effect of Surface Grinding and Joint Sawing on the Durability of Paving Concrete." *Jour. Portland Cement Assoc. Res. and Dev. Lab.*, Vol. 6, No. 1, pp. 16-19 (1964). (1)(b)

8. "Slip Form Process of Concrete Laying Hastens European Road Construction." *Ind. Diamond Rev.*, Vol. 23, No. 268, pp. 66-67 (1963). (1)(c)

   The use of saws to cut joints is discussed.

9. "Streamlined Paving and Joining for Launceston Airport Taxiways." *Australian Civil Eng. and Constr.*, Vol. 6, No. 5, pp. 14-15 (1965). (1)(b)

   The article deals primarily with joint-forming methods.

10. "Tandem Diamond Saws Kept Pace on Record Job." *Roads and Streets*, Vol. 107, No. 6, pp. 63 (June 1964). (1)(c)

    Longitudinal joints were sawed 2¼ in. deep by 3 saws in tandem, each sawing a depth of ¾ in. Transverse joints were sawed to a depth of 2 in. by a set of 4 saws working in series and each sawing one-fourth of a 24-ft lane to full depth. The sawing operation was found to proceed faster during the nights, presumably owing to cooler temperatures.

11. TONS, E., "Joint Sawing and Sealing Bituminous Surfacing." *Res. Rep. No. 33*, Joint Hwy. Res. Proj., Mass. Inst. of Tech., Cambridge, Mass., 9 pp. (June 1960). (1)(a)

12. VOGEL, K. C., "Sawed Contraction Joints for Concrete Airfield Pavements." *Proc. HRB*, Vol. 32, pp. 129-144 (1953). (1)(b)

    Joint sawing experience at Lockbourne Air Force Base is presented.

13. WESTALL, W. G., "Methods of Forming Joints in Portland Cement Concrete Pavement." *Hwy. Res. Record No. 80*, pp. 1-10 (1965). (1)(a)

    There are currently 4 basic methods of forming joints: by hand-tool forming, by sawing, by inserts in the plastic concrete, and by placing preformed joint filler ahead of the concrete. A historical background tracing the development of current practices is provided. Types and purposes of joints are described, and the 4 basic methods of forming are discussed in detail.

IIC. FIELD TESTS

1. FINNEY, E. A., "The History of Road Tests." *Proc. Hwy. Div., Amer. Soc. of Civil Eng.*, Vol. 84, No. HW3, Paper No. 1796, 21 pp. (Oct. 1958). (2)(a)

2. FICKLES, L. A., and RHODES, C. C., "A Field Study of Joint and Crack Resealing Methods and Materials." *HRB Bull. No. 166*, pp. 1-15 (1957). (1)(b)

   Field tests performed by the Michigan State Highway Dept. involved 6 different brands of hot-pour joint sealer and various experimental concrete repairs. A procedure was developed whereby joints and cracks were sandblasted prior to sealing, and then thermostatically controlled pouring equipment was used for applying the sealer. Results indicated that previous failures had been partly due to material deficiences and partly due to inadequate cleaning and sealing operations.

3. GRAHAM, M. D., BURNETT, W. C., and HISS, J. G. F., JR., "Seal Design for Poured Joints in Portland Cement Concrete Pavements." *Proc. HRB*, Vol. 40, pp. 337-370, (1961). (1)(a)

   Field experiments were performed by New York State to determine the effect of the dimensions and spacings of transverse joints in concrete pavements on the performance of the sealer material.

4. GRAHAM, M. D., BURNETT, W. C., HISS, J. G. F., JR., and LAMBERT, J. R., "New York State Experience with Concrete Pavement Joint Sealers." *Hwy. Res. Record No. 80*, pp. 42-48 (1965). (1)(a)

   Field tests were made using a wide variety of sealing materials; performance data are presented. Extruded Neoprene was shown to give excellent service; however, proper installation is important.

5. KILPATRICK, M. J., "Rapid Measurement of Compaction at Joints for Bituminous Concrete Paving." Nat. Bitum. Conc. Assoc., 13 pp., Feb. 19, 1964. (1)(a)

   This article describes a cooperative study made during the 1963 construction season by NBCA, BPR, and 3 state highway departments.

6. MCCAUGHEY, C. W., "Joint-Sealing Maintenance Operations." *Proc. HRB*, Vol. 33, pp. 355-359 (1954). (1)(b)

   Experiments were conducted with cold-applied ready-mixed rubber sealing material.

7. PERKINS, E. T., "Test Project Constructed Utilizing the Contraction Joint Design." *HRB Bull. No. 165*, pp. 35-46 (1957). (1)(a)

   This paper presents the results of tests performed on the Wilbur Cross Highway in Connecticut starting in 1952. Information on pavement movement is included. Several different joint configurations and load-transfer devices were tested.

8. "Report Results on Pavement-Joint Test." *Better Roads*, Vol. 31, No. 9, pp. 21-22 (1961). (1)(b)

   A report on a 20-yr study begun in 1940 is presented.

9. ROBBERS, J. C., and SWANBERG, J. H., "Resealing Joints and Cracks in Concrete Pavements with Hot-Poured Rubber-Asphalt." *HRB Bull. No. 63*, 19 pp. (1952). (1)(b)

   Experimentation and experience by the Minnesota Dept. of Highways in the cutting, cleaning, and resealing of joints and cracks. The study included methods, equipment, materials, and costs.

10. SIMONSEN, J. E., "Construction of Michigan's Experimental Transverse Joint Project I96 from Meridian Road to Wallace Road." *Res. Rep. No. R-428*, Res. Lab. Div., Michigan State Hwy. Dept., Lansing, Mich., 1964. (1)(a)

11. Tons, E., and Roggeveen, V. J., "Field Testing of Materials for Sealing Cracks and Joints in Bituminous Resurfacing." *HRB Bull. No. 166,* pp. 16-27 (1957). (1)(a)

A review of several projects in Massachusetts is presented.

12. Vogelgesang, C. E., and Teske, W. E., "Performance of an Experimental Project to Determine the Efficiency of Several Plain and Reinforced Concrete Pavements." *HRB Bull. No. 165,* pp. 1-34 (1957). (1)(a)

Presents the 23-yr results of a concrete pavement test near Indianapolis, Ind. Several different designs of reinforced concrete pavement, expansion joints, and contraction or dummy joints were incorporated in 9 test sections each 2,700 ft long. Various joint fillers were tried.

13. Wright, P. J. F., "Full-Scale Tests of Materials for Sealing Expansion Joints in Concrete Roads." *Roads and Road Constr.* (British), Vol. 41, No. 485, pp. 138-146 (May 1963). *Hwy. Res. Abst.,* Vol. 33, No. 8, p. 3 (Aug. 1963). (1)(a)

Field tests were made over a 3-yr period in which several different materials were tried in expansion joints of concrete roads with slabs over 100 ft long. Joint movement was measured.

IID. SLURRY SEALS AND SEAL COATINGS

1. Beck, A. H., "St. Louis' Slurry-Seal Experiment." *American City,* Vol. 78, No. 2, pp. 78-81 (Feb. 1963). (1)(c)

2. Chapman, W. E., "Experiences with Slurry Seal." *Pub. Works,* Vol. 94, No. 10, pp. 102-103 (Oct. 1963). (1)(c)

3. Chastain, W. E., and Burke, J. E., "Field Experimentation with Bituminous Undersealing Materials." *Proc. HRB,* Vol. 32, pp. 343-354 (1953). (1)(a)

A field experiment is described in which 3 asphaltic materials were used in conjunction with 2 rates of application. Condition surveys were made prior to, and one year after undersealing. Pumping was materially reduced.

4. Cristofano, S., "Slurry Seal Drops Costs, Boosts Quality." *American City,* Vol. 80, No. 2, pp. 96-98 (Feb. 1965). (1)(c)

5. Fahnestock, T. V., and Davis, R. L., "A New Approach to Subsealing." *Hwy. Res. Record No. 11,* pp. 79-84 (1963). (1)(b)

The development and experience in North Carolina of an asphalt emulsion for subsealing concrete pavements is presented. The emulsion contains a microaggregate or filler that makes the residue from the broken emulsion a mastic which is too stiff to be squeezed through the joints or cracks in the concrete.

6. Gates, T. J., "Cationic Emulsion Used in Slurry Sealing Airfield Surfaces." *Roads and Streets,* Vol. 107, No. 2, pp. 88-90, 92 (Feb. 1964). (1)(c)

7. Gilmore, F. S., "Report on Slurry Seal Applications." Nat. Slurry Seal Assoc., 20 p., 1963. *Hwy. Res. Abst.,* Vol. 33, No. 10, p. 6 (Oct. 1963). (1)(a)

A report is presented on slurry-seal applications observed during a tour of representative areas from coast to coast. A brief review of seal coats in general is included.

8. Glendening, F., "Tests Tougher Sealants at Signalized Intersections." *American City,* Vol. 79, No. 4, p. 109 1964). *Hwy. Res. Abst.,* Vol. 34, No. 6, pp. 6-7 (June 1964). (1)(c)

Results of tests of several slurry seals in Phoenix, Arizona, are given.

9. Harper, W. J., Jimenez, R. A., and Gallaway, B. M., "Effects of Mineral Fillers in Slurry Seal Mixtures." *Hwy. Res. Record No. 104,* pp. 36-59 (1965). (1)(a)

The effect of mineral filler (a common additive) and residual asphalt content on the slurry-seal mixture. A slurry-seal testing machine is evaluated, and a new method of design is developed.

10. Hoge, C., "A Switch to Slurry Seal." *American City,* Vol. 79, No. 4, pp. 104-105 (April 1964). (1)(c)

11. Holberg, A. E., "Emulsified Asphalt Slurry Seal Highways and Airports." *Proc. Canadian Tech. Asphalt Assoc.,* Vol. 111, pp. 51-58 (Nov. 1958). (1)(b)

This article examines the material making up the slurry seal, its mixing and application, and the equipment required.

12. "Jet Runway Gets Fast Weekend Seal Coating." *Roads and Streets,* Vol. 104, No. 9, pp. 84-87 (Sept. 1961). (1)(c)

Experience at Pease Air Force Base in New Hampshire is presented.

13. Kari, W. J., and Coyne, L. D., "Emulsified Asphalt Slurry Seal Coats." *Proc. Assoc. Asphalt Pav. Tech.,* Vol. 33, pp. 502-544 (Feb. 1964). (1)(a)

The results of a field survey of 100 slurry-seal coat projects extending over a 5-yr period are summarized. Data are presented to show that properly designed slurry-seal coats can be used as a surface seal, a mass crack filler, and a temporary wearing surface to prolong the life of a deteriorating pavement in need of major reconstruction. A laboratory design procedure for slurry seal coats, the Wet Track Abrasion Test, is presented, as well as data showing the correlation of this test to field performance.

14. Lohn, R. N., and Nevitt, H. G., "Study of Seal Coating." *Proc. Assoc. Asphalt Pav. Tech.,* Vol. 16, pp. 31-48 (Feb. 1947). (1)(a)

In spite of the good service record of present RC cutback asphalts, the writers believe that they can be improved to perform a better job. With this in mind, an attempt is made to analyze the functions, performance, and costs of seal coats from a theoretical as well as a practical standpoint.

15. Martin, J. T., and Wagener, J. S., "Slurry Seals/Texas Style." *Pub. Works,* Vol. 96, No. 5, pp. 123-124 (May 1965). (1)(c)

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

The new material is a thin application of a hot compound of asphalt and rubber with high elasticity and flexibility and low temperature susceptibility. It is used to patch alligator cracking.

17. McElwee, W., "Thin Coatings Stop Concrete Spalling." *American City,* Vol. 76, No. 9, pp. 107-108 (Oct. 1961). (1)(c)

18. McLeod, N. W., "Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalts and Asphalt Cements." *Proc. Assoc. of Asphalt Pav. Tech.,* Supplement to Vol. 29, pp. 1-150 (1962). (1)(b)

This paper resulted from the author's observations of bituminous surface treatments and seal coats of many thousands of miles of roads in a great many countries. Methods of design and application are covered, and common faults and procedures to avoid them are discussed.

19. "Million-Yard Runway Tar Seal Job." *Roads and Streets,* Vol. 107, No. 4, pp. 120-122 and 129 (April 1964). (1)(c)

Sealcoating of Boston's Logan International Airport is described. Major cracks were routed and filled with a rubberized crack filler before sealcoating.

20. Minarik, W. L., "Uses of Epoxy Resins." *Pub. Works,* Vol. 92, No. 9, pp. 116-118 (Sept. 1961). (3)(c)

21. Nevitt, H. G., "German 'Gussasphalt' Worth Considering for Our Roads." *Roads and Streets,* Vol. 107, No. 2, pp. 93-94 (Feb. 1964). (1)(c)

22. Nevitt, H. G., "Surfacing Repairs and Rehabilitation—4. Slurry Seals." *Roads and Streets,* Vol. 107, No. 10, pp. 70-71 (Oct. 1964). (1)(c)

An analysis and summary of slurry sealing is presented.

23. Ostrander, V. L., "Asphalt Emulsion for Undersealing Rigid Pavements." *Proc. HRB,* Vol. 33, pp. 359-361 (1954). (1)(b)

Briefly described are subsealing, void-filling, and joint filling work done with emulsified asphalt on the New York State highway system.

24. Perry, B. F., "Subsealing of Concrete Pavements." *HRB Bull. No. 322,* pp. 30-33 (1962). (1)(b)

Experiences in New York since 1948 in the restoration of old concrete pavements are presented.

25. Rizzuto, I. F., and Haviland, J. E., "An Investigation of Asphalt Cement Subsealing and Lime-Cement Jacking." *Hwy. Res. Circ. No. 58* (Nov. 1966) 31 pp. (3)(a)

The 2 methods as used in New York are compared; lime-cement jacking was found to be the preferred maintenance procedure.

26. "Road and Bridge Construction in Victoria." *Australian Civil Eng. and Constr.,* Vol. 2, No. 10, pp. 43-47 (1961). (1)(c)

A discussion on crack sealing is included.

27. "Seal and Surface Successfully in Cool Weather." *American City,* Vol. 80, No. 6, pp. 112-113 (1965). *Hwy. Res. Abst.,* Vol. 35, No. 10, p. 11 (Oct. 1965). (1)(c)

28. Stenman, A., "Slurry Seal—A Useful Maintenance Tool." *Pub. Works,* Vol. 94, No. 6, p. 123 (June 1963). (1)(c)

29. "227 Mile Asphalt Sealing Contract." *Roads and Streets,* Vol. 107, No. 2, pp. 73-74, 116 (Feb. 1964). (1)(c)

30. Tallamy, B. D., "Highway Maintenance Programs Are Contemporary Skills." *Pub. Works,* Vol. 93, No. 3, pp. 91-94 (March 1962). (1)(c)

A portion of this article describes the use of undersealing and slurry sealing on the New York Thruway.

31. Uzzle, A. B., Jr., and Porter, I., "Recipe for a Nickle-a-Yard Slurry Seal." *American City,* Vol. 79, No. 2, p. 33 (Feb. 1964). (1)(c)

32. Yoash, P. J., "Sand Seals for Asphalt Surfaces." *Pub. Works,* Vol. 97, No. 5, pp. 121-122 (May 1966). (1)(c)

33. Zube, E., "Seal Coats: Laboratory Contributions Toward Better Performance." *HRB Bull. No. 215,* pp. 14-37 (1954). (1)(a)

A method of controlling the transverse and longitudinal spread rates of the asphalt distributor is presented. Other studies described involve temperature variations, rolling time, screenings degradation, drying conditions and setting time, and screenings adherence.

III. PAVEMENT DESIGN AND BEHAVIOR

IIIA. GENERAL

1. ACI, "Progress with Concrete, 1923-1948—A Symposium." *Jour. Am. Concr. Inst.,* Vol. 19, pp. 693-741 (April 1948). (2)(a)

2. ACI Subcommittee II of Committee 325, "Considerations in the Selection of Slab Dimensions." *Jour. Am. Concr. Inst.,* Vol. 28, No. 5 (Nov. 1956). (1)(a)

3. Burns, C. D., Joseph, A. H., and Womack, L. M., "Proof-Test Section, Columbus Air Force Base." U.S. Army Corps of Eng., Waterways Exper. Station, Vicksburg, Miss. *Tech. Rep. No. 3-490* (1958). (3)(b)

Cracking of pavements under severe loadings was studied.

4. Cashell, H. D., "Trends in Concrete Pavement Design." *Proc. Am. Conc. Inst.,* Vol. 60, pp 501-514 (1963). (2)(b).

A brief survey of joints is included.

5. Evans, M., Jr., and Drake, W. B., "17-Year Report on the Owensboro Hartford Cooperative Investigation of Joint Spacing in Concrete Pavements." Hwy. Mater. Res. Lab., Kentucky Dept. of Hwys., Lexington, Ky., 1954. (1)(a)

6. Gaylord, C. N., and Laughter, C. N., "Performance of Concrete Pavements with 90-ft Contraction Joint Spacing." *Bulletin No. 3,* Eng. Exper. Station, Delaware Univ., Newark, Del., 1952. (1)(a)

7. Gotham, D. E., and Lord, G. W., " Concrete Resurfacing of Concrete Pavement in Various Stages of Disintegration." *HRB Bull. No. 87,* 39 pp. (1954). (2)(a)

Information on joints is included.

8. HRB Project Committee No. 1, "Final Report, Maintenance of Concrete Pavements as Related to the Pumping Action of Slabs." *Proc. HRB,* Vol. 28, pp. 281-310 (1948). (2)(a)

Pumping was found to develop at both expansion and contraction joints on pavements built with expansion provision, whereas comparable pavements built with little or no provisions for expansion developed much less or no pumping. Expansion joints filled with premolded rubber, bituminous impregnated fiber, poured bitumen, and air-chamber filler have been examined. None has been found capable of preventing pumping.

9. "Joint Spacing in Concrete Pavements." *HRB Res. Rep. No. 17-B,* 159 pp. (1956). (1)(a)

Six experimental concrete pavement projects covering a 10-yr period of study are reported.

10. "The AASHO Road Test—Report 5, Pavement Research." *HRB Spec. Rep. No. 61E,* pp. 161-203 (1962). (1)(a)

Subjects covered include cracking, faulting, and pumping of rigid test pavements, and strain and deflection as a function of design, temperature, and load.

11. Hveem, F. N., "Types and Causes of Failure in Highway Pavements." *HRB Bull. No. 187,* pp. 1-52 (1958). (2)(b)

Illustrated examples are presented of typical pavement failures, including several causes of severe pavement cracking.

12. Kelley, E. F., "History and Scope of Cooperative Joint Spacing in Concrete Pavements." *Proc. HRB,* Vol. 20, pp. 333-336 (1940). (1)(a)

13. Lokken, E. C., "What's New in Concrete Paving." *Civil Eng.,* Vol. 34, No. 3, pp. 54-57 (1964). (2)(b)

A brief survey of joints and jointing equipment is presented.

14. Moreell, B., Murray, J. J., and Heinzerling, J. E., "Experimental Prestressed Concrete Highway Project in Pittsburgh." *Proc. HRB,* Vol. 37, pp. 150-193 (1958). (3)(a)

The problems of expansion joints for prestressed slabs are covered. Changes in length to be accommodated were measured in the field. A joint consisting of laminations of rubber and steel resting on a long flexible sill was developed.

15. Portland Cement Assoc., *Concrete Pavement Design.* Chicago Ill., pp. 61-66, 1951. (2)(b)

16. Portland Cement Assoc., *Concrete Pavement Inspector's Manual.* Chicago, Ill., pp. 24-36, and 39, 1954. (3)(b)

17. Portland Cement Assoc., *Concrete Pavement Manual.* Chicago, Ill., pp. 61-63, 1955. (3)(b)

18. Portland Cement Assoc., *Pavements for City Streets.* Chicago, Ill., 1963. (2)(b)

19. Portland Cement Assoc., *Joint Design for Concrete Pavement.* Chicago, Ill. (1)(a)

20. Raev-Bogoslovskii, B. S., et al., "Rigid Airfield Pavements." *Avtotransizdat* (Moscow), 322 pp., 1961. (In Russian.) (2)(b)

Both slab and joint design and tests are covered.

21. Sawyer, D. H., "A Concrete Pavement Without Transverse Joints." *Rep. No. 5,* Hwy. Res. Lab., Kentucky Dept. of Hwys., Lexington, Ky., 1956. (2)(a)

22. Seredin, Y. V., "Interaction Between Concrete Slabs and the Base." *Avtom. Dorogi,* Vol. 26, No. 1, pp. 22-24 (1963). (In Russian.) (2)(b)

23. Shields, B. P., and Anderson, K. O., "Some Aspects of Transverse Cracking in Asphalt Pavements." *Proc. Canadian Tech. Asphalt Assoc.,* Vol. 9, pp. 209-225 (1964). (1)(a)

24. U.S. Army Corps of Engineers, "Engineering and Design of Rigid Air-Field Pavements." *EM 1110-45-303,* Feb. 3, 1958. (2)(b)

25. Univ. of Mississippi, "The Response to Questionnaire—Control of Pavement Movements Adjacent to Structures." *Spec. Rep. No. 2,* Feb. 15, 1965. (1)(a)

Presents a summary of a response by the State highway departments pertaining to damage of structures from encroachment of rigid pavements. Such damage is widespread and a source of concern in some States. Expansive concrete, alkali-aggregate reaction, infiltrated solids in transverse joints, too few expansion joints, and downhill creep are prominent factors mentioned.

26. U.S. Army Corps of Eng., "Rigid Pavements for Roads, Streets, Walks, and Open Storage Areas." *EM 1110-345-292,* June 30, 1961. (2)(b)

27. U.S. Navy Bureau of Yards and Docks, "Joints, Reinforcement and Mooring Eyes in Concrete Pavements." *NAVDOCKS Specification 46 Yd,* Sept. 1961. (2)(b)

28. Young, L. E., "A Sliding Joint, Prestressed Concrete Pavement." *Jour. Prestressed Concr. Inst.,* Vol. 6, No. 3, pp. 92-97 (Sept. 1961). *Hwy. Res. Abst.,* Vol. 31, No. 10, pp. 8-9 (Nov. 1961). (3)(a)

A paving system using precast concrete slabs in the form of equilateral triangular prisms is described. A thin layer of plastic material is used to seal the joints and the pavement is post-tensioned. Joint movement occurs as a sliding action.

IIIB. THERMAL AND MOISTURE EFFECTS

1. Allen, H., "Report of Committee on Warping of Concrete Pavement." *Proc. HRB,* Vol. 25, pp. 199-250 (1945) (1)(a)

Distortions at pavement joints were always associated with conditions which permitted water to pass through the joints to the subgrade; however, warping did not necessarily occur at leaky joints. Curling of the pavement slab due to internal forces within the slab is not enough to cause the pavement distortions observed. Curling due to temperature differentials between the top and bottom of slabs could account for only a small part of distortions observed, and curling due to moisture differentials is very small. It was found that warping was caused by swell or shrinkage of the subgrade soil.

2. Croldbeck, A. T., and Jackson, F. H., "The Expansion and Contraction of Concrete and Concrete Roads." *Bull. 532*, U.S. Dept. of Agri. (1917). (1)(c)

3. Friberg, B. F., "Frictional Resistance Under Concrete Pavements and Restraint Stresses in Long Reinforced Slabs." *Proc. HRB*, Vol. 33, pp. 167-184 (1954). (1)(a)

   Temperature contraction of short pavement slabs is not greatly diminished by frictional-tension stress. But long pavement slabs, as used in continuously reinforced concrete pavements, actively contract and expand only for some hundreds of feet near each end. The effects of thermal change, friction, and elasticity are discussed.

4. Harr, M. E., and Leonards, G. A., "Warping Stresses and Deflections in Concrete Pavements." *Proc. HRB*, Vol. 38, pp. 286-321 (1959). (1)(a)

   The development of a theory whereby stresses and deflections in concrete pavements subject to temperature and moisture gradients can be computed. Good agreement has been shown between observed and computed deflections.

5. Hatt, W. K., "The Effect of Moisture on Concrete." *Trans. Am. Soc. of Civil Eng.*, Vol. 89, pp. 270-315 (1926). (1)(a)

   Tests on a concrete road slab under controlled environmental conditions were conducted at Purdue Univ. Warping and surface deformations were measured as a result of a nonuniform distribution of moisture.

6. "The AASHO Road Test—Report 4, Bridge Research." *HRB Spec. Rep. No. 61D* (1962) pp. 177-183. (1)(a)

   Temperature strain tests on highway bridges are presented.

7. Hveem, F. N., "Slab Warping Affects Pavement Joint Performance." *Jour. Am. Conc. Inst.*, Vol. 47, pp. 797-808 (1951). (1)(a)

8. Illinois Div. of Highways, "Investigation of Slab and Subgrade Movement Under Low Temperatures." *Report of Studies of Frost Action in Highways in Three Northern and Central Illinois Districts* (Unpublished), 1924. (1)(c)

9. Koenitzer, L. H., "Elastic and Thermal Expansion Properties of Concrete as Affected by Similar Properties of the Aggregate." *Proc. Am. Soc. for Testing and Mater.*, Vol. 36, Part 2, pp. 393-410 (1936). (1)(c)

10. Lang, F. C., "Temperature and Moisture Variations in Concrete Pavements." *Proc. HRB*, Vol. 21, pp. 260-271 (1941). (1)(a)

   A record was obtained in Minnesota of movement resulting from changes in temperature and moisture in a concrete pavement and underlying subgrade. Temperatures were recorded at 6 places in the 7-in. slab and 5 places in the subgrade every 6 min for 1 yr. Moisture content was determined at the center of the slab and at 3 places in the subgrade.

11. Lu Nung Yuen, "Comparison of the Thermal and Moisture Expansion of Concrete and Stone." Master's thesis, Purdue Univ., Lafayette, Indiana, 1948. (1)(a)

12. Meyers, S. L., "Thermal Coefficient of Expansion of Portland Cement." *Ind. and Eng. Chem.*, Vol. 32, pp. 1107-1112 (1940). (1)(a)

13. Moncher, F. L., Lissner, H. R., and Lipson, C. H., "Long-Time Elastic Strain Gage Measurements on Reinforcing Rods at the Packard Proving Grounds Test Track." *Proc. Soc. for Exper. Stress Analysis*, Vol. 6, No. 1, pp. 29-34 (1948). (3)(a)

14. Schink, W., "Stresses in Joints in Concrete as a Result of Shrinkage and the Method Used for their Measurement." Charlottenburg (Berlin), Zementverlag, 1939. (1)(c)

15. Sebastyan, G. Y., "Portland Cement Concrete Airport Pavement Performance in Canada." *Hwy. Res. Record No. 46*, pp. 101-124 (1964). (1)(a)

   Experimental observations are included on the curling of portland cement concrete pavements due to variations in temperature gradient within the pavement.

16. Teller, L. W., and Sutherland, E. C., "Observed Effects of Variations in Temperature and Moisture on the Size, Shape, and Stress Resistance of Concrete Pavement Slabs." In *The Structural Design of Concrete Pavements*, Reprinted from *Pub. Roads*, Vol. 16, Nos. 8, 9, and 10, Vol. 17, Nos. 7 and 8, and Vol. 23, No. 8, pp. 15-43 (1935-1942). (1)(a)

   A series of 6 articles concerning the state of the art in concrete pavement design is presented. The second article (Vol. 16, No. 9) presents detailed data on temperature and moisture effects.

IIIC. REFLECTION CRACKING

1. Bone, A. J., and Crump, L. W., "Revere Resurfacing Project: An Experiment in Control of Reflection Cracking in Bituminous Surfaces over Concrete." *Res. Rep. No. 8*, Joint Hwy. Res. Proj., Mass. Inst. of Tech., Cambridge, Mass., June 1954. (1)(a)

2. Bone, A. J., Crump, L. W., and Roggeveen, V. J., "Control of Reflection Cracking in Bituminous Resurfacing over Old Cement-Concrete Pavements." *Proc. HRB*, Vol. 33, pp. 345-354 (1954). (1)(a)

   The causes of reflection cracking are described and several experimental techniques for its control are given. Particular emphasis is placed on the strains imposed in bituminous concrete surfaces by the horizontal movement of concrete slabs at joints and cracks due to temperature changes. Measurements were made of joint openings and closings in concrete pavements to determine the magnitude of strains imposed upon the resurfacing. The authors conclude that reflection cracking can be eliminated only by the development of new techniques for handling joints in resurfacing. Preliminary conclusions are drawn as to the effectiveness of the experimental techniques described.

3. BONE, A. J., and CRUMP, L. W., "Current Practices and Research on Controlling Reflection Cracking." *HRB Bull. No. 123,* pp. 33-38 (1956). (1)(b)

A survey is presented of existing and proposed methods for controlling or preventing reflection cracks and for sealing them.

4. GOULD, V. G., "Summarized Committee Report 1948-1960: Salvaging Old Pavements by Resurfacing." *HRB Bull. No. 290,* pp. 1-14 (1961). (1)(a)

5. HOUSEL, W. S., "Design, Maintenance, and Performance of Resurfaced Pavements at Willow Run Airfield." *HRB Bull. No. 322,* pp. 34-52 (1962). (1)(a)

A long-term research and observation program is described. Experimentation with bituminous resurfacing included the use of wire-mesh reinforcement, of varying thicknesses of surface, and of epoxy resins and other solvent-resistant materials. Periodic surveys were made to determine reflection cracking.

6. JOHNSON, R. D., "Thin Overlay Bituminous Macadam for Control of Reflex Cracking." *Hwy. Res. Rec. No. 150,* pp. 20-24 (1966). (1)(b)

Bituminous macadam is shown to be a most effective overlay for deterring reflex cracking. Observations were carried out over 4 yr.

7. KIMBLE, F. W., "Conditioning an Existing Concrete Pavement for Bituminous Resurfacing." *HRB Bull. No. 123,* pp. 11-18 (1956). (1)(b)

The actual work performed in preparing a rigid pavement for resurfacing is discussed, and the 4-yr history of reflection cracking for the resurfaced highway is presented.

8. RANSON, R., "Minimizing Crack Reflections." *Pub. Works,* Vol. 94, No. 11, pp. 87-88 (1963). (1)(c)

Pavements not subjected to the kneading action of vehicular traffic may be more prone to cracking than streets and highways. Nevertheless, a thin bituminous overlay of a playground area is described in which the new surface is placed over a previously overlaid portland cement pavement which had excessive reflection cracking. A bond breaker was employed over existing cracks. Only a few remote cracks have occurred in the 3 yr since reconstruction.

9. ROBERTS, S. E., "Cracks in Asphalt Resurfacing Affected by Cracks in Rigid Base." *Proc. HRB,* Vol. 33, pp. 341-345 (1954). (1)(b)

Field-test observations on the occurrence and control of reflection cracks are reported.

10. ROGGEVEEN, V. J., and TONS, E., "Progress of Reflection Cracking in Bituminous Concrete Resurfacings." *HRB Bull. No. 131,* pp. 31-45 (1956). (1)(b)

The results of periodic condition surveys conducted on twenty-five 1000-ft samples are presented. It is concluded that 90 percent of the possible potential reflection cracking will take place within the first 5 or 6 yr.

11. SIMON, M., "Laying of Rolled Asphalt over Concrete Pavements." *Melyepitestudomanyi Szemle,* Vol. 12, No. 12, pp. 538-543 (1962). (In Hungarian.) (1)(c)

Results are summarized of an investigation to find ways of preventing cracks in asphalt overlays on concrete.

12. TONS, E., and KROKOSKY, E. M., "A Study of Welded Wire Fabric Strip Reinforcement in Bituminous Concrete." *Proc. Assoc. of Asphalt Pav. Tech.,* Vol. 29, pp. 43-80 (1960). (1)(a)

Paper *a* discusses the influence of horizontal and vertical base slab movements on the formation of reflection cracks in bituminous concrete; paper *b* summarizes some hypothetical cases of the behavior of welded-wire fabric strip reinforcement placed to resist tensional and shear forces induced by the above-mentioned movement; paper *c* discusses laboratory and field research data obtained.

13. TONS, E., BONE, A. J., and ROGGEVEEN, V. "Five-Year Performance of Welded Wire Fabric in Bituminous Resurfacing." *HRB Bull. No. 290,* pp. 15-38 (1961). (1)(b)

Various styles of welded-wire fabric were placed within a 3-in. bituminous concrete overlay at various locations. The best performance was found to reduce transverse cracking to about one-eighth that found in control sections; longitudinal cracking was negligible.

14. VELZ, P. G., "Effect of Pavement Breaker Rolling on Crack Reflectance in Bituminous Overlays." *Hwy. Res. Record No. 11,* pp. 85-88 (1963). (1)(b)

A heavy roller was used experimentally to crack old portland cement concrete pavement and to seat it on subgrade before resurfacing with bituminous mixtures in Minnesota in 1959. Subsequent performance of the overlays is discussed.

15. VICELJA, J. L., "Method to Eliminate Reflection Cracking in Asphalt Concrete Resurfacing over Portland Cement Concrete Pavements." *Proc. Assoc. of Asphalt Pav. Tech.,* Vol. 32, pp. 200-227 (1963). (1)(b)

Discussed is the use of various crack-preventing devices, such as expanded wire mesh, sheet metal, wax paper, aluminum foil, stone dust, and sand, on 3 resurfacing projects.

16. WILSON, J. O., "Crack Control in Bituminous Overlays on Rigid Pavements." *HRB Bull. No. 322,* pp. 21-29 (1962). (1)(b)

A study is presented of the effects of sawing and sealing reflection cracks over transverse joints in rigid pavement. Results after 3 yr appear favorable.

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