

Blowups: Still a Problem?

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INTRODUCTION

Blowups of Portland cement concrete pavements have been a problem encountered by the Indiana State Highway Commission and many other highway departments for many years. Blowups, an annoyance to say the least, are detrimental to the riding quality of the pavement and sometimes are hazardous to the road user. Expensive corrective maintenance is often required to completely alleviate the problem, the result being that temporary measures are widely used which satisfy the public at lower cost, but do not eliminate the problem completely.

It is a matter of common experience that blowups continue to develop after a concrete pavement is resurfaced with a bituminous overlay. There are some data available which indicate that blowup activity is increased by the resurfacing in some cases. As yet no definite work has been conducted which relates occurrence of blowups with bituminous resurfacing. Work pertaining to concrete pavements overlaid with Portland cement concrete by Lewis (1)* states: "The deterioration that has taken place to a greater extent in the resurfacing than in the full depth pavement includes scaling, D-line cracking, and blowups." Results of a survey in Missouri (2), although indicating that no blowups were found in any of their concrete resurfacings, did show that excessive expansion developed in the underlying old pavement.

Bituminous overlays have long been the primary means of upgrading deteriorating Portland cement concrete pavements, and it is inevitable that many thousands of miles of interstate highways, state and local roads will need resurfacing. Hence, there exists a need for investigating

* Numbers in parentheses indicate references in the bibliography at end of this paper.

the blowup phenomenon—is it still a problem, and if so, what can be done about it?

DEFINITION OF BLOWUPS

Owing to the fact that blowups have come to be known by several different names which could result in some confusion, a discussion of the classes and mechanics of blowups is presented here. The authors do not hope to convey to the reader a detailed understanding of the mechanics of a blowup, but simply to present the most widely held concepts in an effort to lay a foundation upon which a later discussion of the factors involved can be built.

Blowups are caused by compression stresses resulting from heat and water, and they generally occur at a joint or crack. It is known that intrusion of foreign material, water, and chemical deicing solution into joints and cracks causes extensive damage to rigid pavements. According to Cook and Lewis (3), "The intrusion of incompressible soils 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, non-uniform, concentrated stresses in the concrete adjacent to the joint opening ultimately results in spalling and progressive disintegration of the concrete." Because of this restrained movement, "the 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." The rise can be from a fraction of an inch to more than a foot in the extreme case.

Research conducted in New York (4) points out two major classes of blowups in rigid pavements. The first type of blowup occurs typically as illustrated in Figure 1. It is usually a buckling and/or shattering (sometimes violent) of two adjacent pavement slabs. This type of blowup may occur in unresurfaced or resurfaced pavements.

A second type of blowup occurs primarily in resurfaced pavements (Figure 2), and is commonly referred to as "humps", "bumps", or "high joints". A vertical displacement of up to three inches may occur in the overlays. While this type is not usually a serious hazard to traffic, it does detract from the riding quality of the pavement and requires considerable maintenance. It apparently results from compression and upward extrusion of the deteriorated concrete rubble, which, if sound, would probably have accommodated the compression or in some instances developed a blowup of the major class (4).

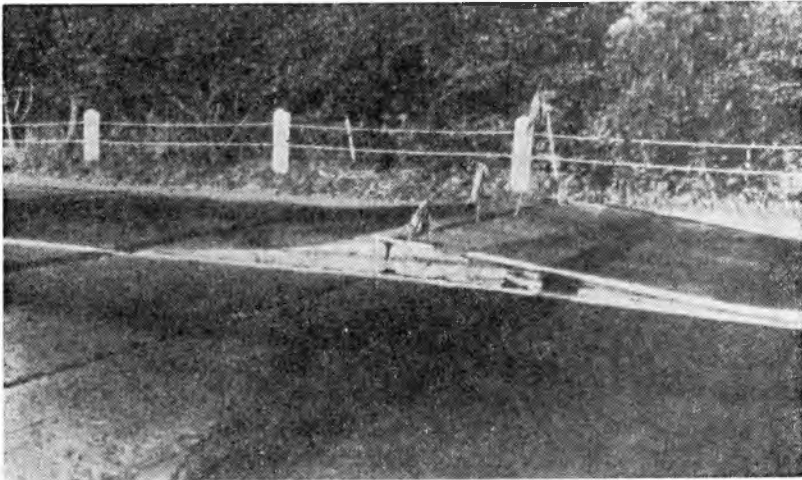


Fig. 1. Type I. Blowup of a Concrete Pavement

It should be pointed out that while a type I blowup is easily recognizable and distinct in appearance, type II blowups can often resemble other pavement failures; for example, faulting in resurfaced pavements. Its mechanisms are unique, however, and present a problem entirely its own.

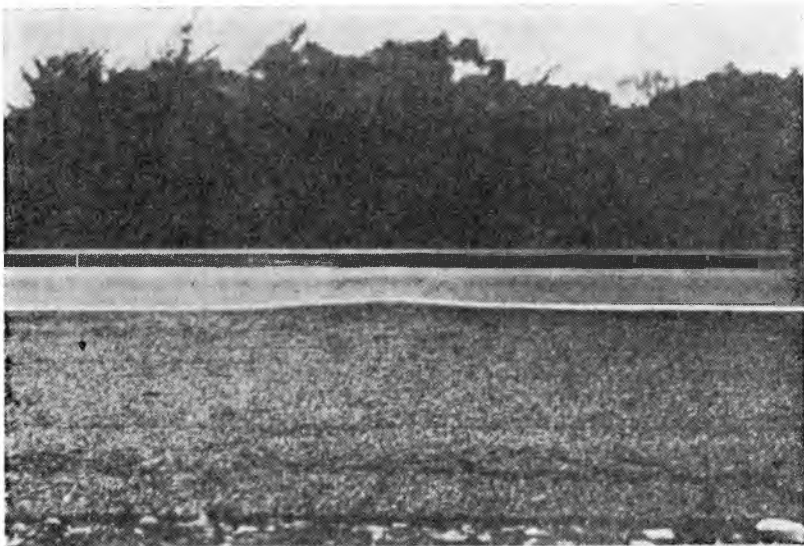


Fig. 2. Type II. Blowup of Resurfaced Concrete

HISTORY OF DESIGN OF CONCRETE PAVEMENTS IN INDIANA

In any study of the performance of pavements, one must take into account the history of what has been done to improve the situation. Consequently, a trace of the major design aspects of concrete pavements in Indiana provides a clearer picture of what designers and researchers have innovated to enhance the performance of pavements. Of particular concern here is blowups; the following discussion points out design changes that were intended to directly benefit this problem. Table 1 summarizes the important stages of concrete pavement design in Indiana.

Prior to the formation of the Indiana State Highway Commission in 1919, the responsibility for construction of highways in Indiana rested directly with the counties (6). During these early years of concrete construction in Indiana, no provision was made for expansion space for blowup control. There were no well accepted guidelines for design, and very little was known about the mechanics of a rigid pavement under loads. Prior to 1923, no reinforcing steel was used in concrete pavements with 6-8-6 and 7-9-7 cross sections. In 1923 the ISHC developed their first pavement design standard, which included No. 6 diameter marginal bars, as well as No. 4 diameter deformed bars placed transversely at four-foot centers. This pavement, placed directly on the subgrade, was 18 feet wide with a uniform seven-inch thickness. This standard design remained unchanged for three years. In 1926 the need for a longitudinal joint to control cracking became apparent, and the designers deleted the transverse bars and added a longitudinal joint tied with No. 5 bars spaced five feet on centers. Also, the concept of the thickened edge pavement to relieve edge stresses was put into use with the first 9-7-9 pavement for high traffic loads.

From 1926 to 1934, the previous design concepts were used in all pavements constructed by the state. In cases where heavy traffic was anticipated, pavements differing only in center thickness and width were designed, with widths up to 40 feet in use. Gradually, the 20-foot pavement became more popular, and by 1934 it was the minimum width. During this period, pavement expansion in some cases caused severe distress at bridge abutments. For this reason expansion joints three inches in width, filled with bituminous material and doweled with $\frac{3}{4}$ -inch diameter bars spaced $3\frac{1}{2}$ feet on centers, were specified 50 feet from each end of a bridge abutment. This constituted the first transverse joint used to relieve compressive stresses and most likely helped to control to some extent the blowup activity.

By 1934, however, it became apparent that expansion joints at bridges alone could not control contraction and restraint cracking and blowups. Therefore, $\frac{3}{4}$ -inch diameter doweled expansion and contraction joints were introduced into the standards, with each alternating at 40-foot spacings. Also, use was first made of temperature reinforcement to control the extent of crack openings, while marginal bars were deleted.

The period from 1934 to 1941 saw an extensive use of the 20-foot pavement with expansion and contraction joints, longitudinal joints tied with No. 5 bars as before, and temperature reinforcement. Several minor alterations to this design were incorporated into the standards, including various thickened edge sections and numerous combinations of joint spacings. At this point, it is not known what effect these variations had on the occurrence or relief of blowups.

With the advent of World War II came a drastic change in the design of highways constructed of reinforced concrete pavement. Due to the dramatic increase in the demand for steel, for armament purposes, the use of steel in pavements, except for longitudinal tie bars, was abandoned from 1941 to 1945. Designers, realizing that load transfer across joints would have to be accomplished by grain interlock, reduced contraction joint spacing to 20 feet to limit crack opening. Undoweled expansion joints were spaced at 120 feet with no load transfer provided. Finally, it was during this period that use of the 22-foot pavement became predominant to accommodate increased truck traffic.

Pre-World War II design practices were resumed in 1946 with two major exceptions: first, a granular subbase was used under the pavement, and second, expansion joints were deleted. Both changes were aimed at the pumping problem that became severe at this time. In some cases the subbase was built in a "trench". Later the subbase was extended through the shoulder to provide drainage, with sub-drains first extensively used about 1951. During the period 1946 to 1957 the pavements were widened to 24 feet and became uniformly thick at nine inches.

With the results of the Woods, Sweet and Shelburne (15) study, made available in 1946, Indiana put stricter control over the coarse aggregate used in paving, with those particularly bad sources being eliminated as causes of blowups. Distributed steel was increased in size to No. 2 wires longitudinally and No. 4 wires transversely, while tie bars were reduced in size to No. 4 bars spaced at $2\frac{1}{2}$ -foot intervals. In 1957 the size of dowel bars was increased to $1\frac{1}{4}$ inches in diameter.

Pavement design remained unchanged until the mid 60's when thicknesses of ten inches were introduced as well as the first continuously reinforced concrete pavements. This latter type of pavement is constructed without any joints and, as a result of the high steel percentage, it cracks at five- to ten-foot intervals. It is felt by many officials that this design will eliminate the problem of excessive expansion and blowups, but more time is needed to evaluate its performance. This is especially true with regard to bituminous overlays, since presently there are no resurfaced continuously reinforced pavements.

It is hoped that research currently in progress will bring out the importance of pavement design on blowup activity, and enable designers to take advantage of past history to better design future pavements.

FACTORS INFLUENCING BLOWUP OCCURRENCE

As was pointed out earlier, the immediate cause of a blowup is compression in the road combined with a mechanism to concentrate the compression in a small area. This cause, in turn, arises from other factors, and in fact, is most likely a result of a combination of several factors which are responsible for a blowup. The important factors considered to be an influence on blowups are:

1. Climate: temperature and moisture content of the slab
2. Type and number of the joints
3. Age of the pavement
4. Type of aggregate used in the concrete
5. Type of subgrade
6. Subbase: type and permeability, and use of drains
7. Traffic
8. Maintenance: type and frequency (primarily joint sealing)
9. Pavement thickness
10. Type of shoulders

These factors are not given in any order or importance; each factor will be discussed with emphasis on its possible influence on blowups.

Climate

There are several important aspects which come under the general heading of climate. Of most significance is the factor of temperature. Increases in temperature result in expansion of a concrete slab. A summary of a study on pavement blowups in Arkansas (6) states, "Blowups seem to be caused by a combination of temperature and moisture in the concrete slab." Graham reports (5), "The consensus

among the County Resident Engineers was that the cause of pavement blowups is high temperatures." This study also shows that over 80 percent of blowups investigated occurred at atmospheric temperatures above 90° F. Similar results were found in the Illinois study (7) and the British study (8).

An interesting conclusion was drawn from a Connecticut study (14) which states, "The temperatures at which adjacent lanes are placed may influence pavement performance. High uniformity of placement temperature between lanes results in low frequency of failure. Consequently, a large spread between the placement temperatures in adjacent lanes gives rise to high frequency of failure." A quote from Engineering News-Record (9), although published nearly 50 years ago, has significance today: "The most frequent occurrence of blowups is when a hot day is followed by a rainy night succeeded by another hot day, causing temperature and moisture expansion." It must also be recognized that cold temperatures, which cause contraction and subsequent opening of joints and cracks, can result in the infiltration of foreign matter into joints. This aspect will be discussed later.

The second aspect of climate of major importance is moisture, primarily in the form of rain, but not to be overlooked, is snow. As previously stated (6, 9), moisture in combination with temperature is a major cause of blowups. However, in work concerning concrete resurfacing (1, 2, 10), the cause of an increase in blowup activity was probably not due to an increase of temperature, since the new surface was of similar material to the old, but it is likely that the moisture content increased. A flowing film of water was found by Gotham and Lord (2) at several places between the two layers of concrete (11).

Further evidence of the importance of water is given by the Arkansas study (6) when maintenance forces found that the bottom portion of each slab, where a blowup had occurred, was saturated. Illinois (7) found that 75 percent of all blowups were reported to have occurred within a week following a rainfall.

No evidence has been reported which links snowfall to blowups specifically, but Sweet (12) shows that freezing and thawing, obviously dependent on moisture being present, reduces aggregate strength with subsequent deterioration of the concrete, which can lead to blowups.

Joints

There are several aspects of joints which have a direct bearing on the occurrence of blowups, including: (1) the presence or absence of expansion joints; (2) spacing between joints; (3) faulty joint con-

struction and operation; and (4) infiltration of grit into joints. With regard to the first factor, Stott and Brook (8), in their study of the blowup problem in several states, concluded, "The evidence obtained does not make it possible to be specific on the effect of omitting expansion joints from concrete roads. Experience in the U. S. A. indicates that blowups have occurred on concrete roads whether or not expansion joints were used."

Concerning joint spacing, there was some thought among state engineers that a shorter spacing of contraction joints made blowups less likely because joint movements were less (8). Research in Maryland (13), Illinois (7), Connecticut (14), and Arkansas (6) also substantiate this conclusion.

Few engineers feel that faulty construction of joints other than expansion joints are a serious cause of blowups. The Bureau of Public Roads said they were concerned about the corrosion of dowel bars which reduces load transfer at joints (8). Unfortunately, designs that have shown the best promise in reducing blowups have not been capable of satisfying other criteria necessary for adequate overall performance in some cases. Structural weaknesses that developed at expansion joints had proven discouraging to their use (7). On the other hand, expansion joints are used extensively in New Jersey with great success.

Many engineers hold the opinion that a major cause of blowups is infiltration of incompressible material into joints and cracks. Infiltration occurs mainly because of the unsatisfactory performance of sealing compounds (8). One premise is that blowups occur because the incompressible material that lodges in open joints and cracks restricts subsequent expansion and causes disruptive stresses (4). In actual inspections of blowups in Arkansas (6) and New York (5), it was evident that base material was mixed with the deteriorated concrete at the joint. This action may be responsible for many blowups, but it does not explain why a pavement can become blowup susceptible after being resurfaced, and joint failures do not themselves preclude other mechanisms also coming into play (11). Pumping can be a major contributor to joint infiltration.

Age

Most research results on blowups point out that age is a major variable, but no definite relationship has been established. According to Stott and Brook (8), "It appears that the frequency of blowups increases with age of the road, although there is not sufficient evidence to establish a definite relationship. Generally, a road is three to nine years old before blowups begin to occur, although some cases were

reported where the road was only about one year old." Likewise, in Arkansas, blowups are reported to start occurring in a pavement about four years from the construction date. In the British (8), Illinois (7), and Maryland (13) studies, the factor of age was taken directly into account along with blowups per mile. The measured variable became blowups per mile per year. The Illinois report (7) attempted to relate age to blowups by looking at changes in pavement design over the years and the corresponding number of blowups reported for particular types of design. However, because of the usual practice of transitional changes in design, some difficulty was experienced in assigning blowups to designs during transitional years. It can be seen from the experiences of several states that age plays a major role in the frequency of blowup occurrence, particularly with regard to age of overlays.

Aggregates

Research conducted in Indiana has been concentrated on correlating blowup occurrence with aggregates, primarily coarse aggregate. Woods, Sweet and Shelburne (15) found an outstanding correlation between certain sources of coarse aggregate and susceptibility of the pavement to blowups. On the other hand, outstanding correlation was also found between certain sources of coarse aggregate and pavements with a lack of blowups. It was found that both stone and gravel coarse aggregates could contribute to blowup activity. Sweet and Woods (16) concluded, "Aggregate has an important influence on the durability of concrete." Further research by Sweet (17) goes into great detail about the effect of coarse aggregate on concrete durability and subsequently its susceptibility to blowups. The British investigators (8) found that the use of expansive and unsound aggregates considerably increases the number of blowups. It must be pointed out that the Illinois study (7) found no correlation between source of coarse aggregate and blowups, but on the other hand, the possibility could not be ruled out.

The Indiana study (15) found that no one particular type of aggregate was more significant as a bad factor than another, but Maryland (13) found "pavements having gravel aggregate had a higher average frequency of apparent end failures (repaired blowups) in both surveys than did pavements with either stone or slag aggregate." A similar difference in findings regarding fine aggregate effect on concrete durability exists. No positive correlation between blowups and fine aggregate could be found in Illinois (7) or Indiana (15), but Sweet and Woods (16) state, "the grading, particle shape, and surface characteristics of the fine aggregate have a marked influence on durability of pavements." Further research in each of these areas is needed

to dispell these discrepancies. Presently, research has shown no significant influence on blowups by source and/or type of cement used.

Subgrade Soil

Another main variable to be considered is the predominant subgrade soil. Walbeck and Stromberg in Maryland (13) did some extensive investigation of this factor, grouping soils into three general classes: sandy, silty, and clay. With respect to end failures (repaired blowups) they found that sandy soils had the worst performance, followed by silty soils, and finally clay soils with the best performance. From the standpoint of moisture, the clay soils should be the worst, suggesting that other factors are more significant.

Hensley (6) concluded in the Arkansas study that "Blowups occurred more frequently where the pavement was laid over a moderately permeable subgrade, which had a medium-high plasticity index." Conversely, in Illinois (7) no evidence was found that subgrade soil was significant. Finally, Woods et al (15) stated, "Soil is not a significant factor in the susceptibility of a pavement to blowing up, this failure having occurred on a wide range of soil texture. However, disintegration of those pavements susceptible to blowups was more rapid on plastic soils than on the more granular types."

Subbases

Of primary concern here is the presence or absence of a granular subbase or base. None of the literature reviewed has shown this to be significant. However, in the case where subbases or bases were used, the British (8) and Arkansas (6) studies reported the presence of wetness in the subbases at blowup sites. The Maryland study (13) further concluded that "roadways with a stone subbase perform better than those with gravel or local sand borrow subbases, and roadways with gravel subbases perform slightly better than those with local sand borrow." One might speculate that pumping and, thus infiltration into joints by subbase material would account for this.

Traffic

Concerning this factor, Woods, Sweet, and Shelburne (15) found "The effect of traffic has been observed to be secondary in nature. Blowups have occurred on both lightly and heavily traveled roads. Conversely, many roads, built before 1935 and subjected to wide ranges of traffic conditions, are without blowups. However, it has been observed that on highways where blowups are prevalent, accompanying concrete deterioration is more severe on the heavily traveled roads." Neither of the studies in Maryland (13) nor Illinois (7) found

traffic, by itself, to be significant, but in conjunction with age, it became a factor. Bowers, in the Connecticut study (14) had an interesting observation when he stated, "Pavements with two lanes, where lane distribution of traffic is more uniform, tend to have lower rates of compression failure."

Maintenance

It has been suggested that maintenance of a road, primarily in the area of snow and ice removal, and subsequent use of deicing agents, has a connection with blowup activity. As yet, no research has been conducted in this region. From the standpoint of infiltration, it seems reasonable to conclude that incompressible material lodges in cracks and joints, leading to excessive compressive stresses. Similarly, deicing chemicals accelerate the deterioration of concrete, which is believed to increase blowups. This problem has special significance in northern climates, and research is needed to determine if preventive maintenance in the form of joint cleaning and sealing is effective in reducing compression failures.

Pavement Thickness

Pavement thickness as an influencing factor of blowups has had little consideration. Generally, a pavement is designed with the minimum thickness required to carry the anticipated loads, with the cost of additional thickness to enhance performance characteristics prohibiting such construction. Possibly, increased cross-sectional area at a joint resulting from thicker pavements may have an effect. Also, increased thickness results in increased stiffness of the slab.

In work concerning the performance of bituminous overlays on Portland cement concrete, Goetz and McLaughlin (18) found that thicker overlays enhanced the performance of the pavement. In each of these cases, general performance only, and not blowups specifically, was evaluated. Similar results regarding blowups are only speculation.

Shoulders

In the discussion concerning infiltration into joints, it was suggested that material from the subbase or base may be a source of this. Another possible source, however, is the gravel or stone shoulder of the road. This possibility was recognized in the Maryland study (13) when they considered four types of shoulders and each one's effect on pavement performance. At first glance, the results are surprising, in that they found paved shoulders (bituminous concrete, curb and gutter) to contain significantly more end failures than surface treatment, gravel, or stone shoulders. But further analysis showed these results to be con-

nected to the type of coarse aggregate used, and thus, no definite conclusion was reached about the effect of shoulder type.

Conclusions drawn by Bowers state in part (14), "The middle lane of the turnpike contains more compression failures than other lanes. This is thought to be caused by stress transfer from the two adjacent lanes into the middle lane via the longitudinal tie bars." These conclusions could conceivably be expanded to include paved shoulders and storage lanes.

PRESENT RESEARCH ON BLOWUPS

As was pointed out earlier, blowups in resurfaced pavements have been a constant problem for maintenance forces in Indiana over the years. Many state officials speculate as to the cause of these blowups, but as yet no conclusive investigation has been carried out to determine exactly what factors are important. In an attempt to answer this question, a study has been formulated under the supervision of the Joint Highway Research Project at Purdue University to investigate blowups in resurfaced pavements. A brief discussion of the objectives of the project is presented here.

The project is divided into three phases. The first phase consists of a field study of pavement performance to establish correlations of the previously discussed factors with extent of blowup activity. To do this, all concrete pavements in the Indiana State Highway System were located through the Road-Life Records in Indianapolis. These records enable the roads to be divided into groups with each pavement in the group having similar characteristics. Complete information on each section will be compiled, coded, and keypunched for the computer.

The entire "population" will be sampled according to certain factors believed to have the most bearing on the problem. Field surveys will be conducted on these samples. Upon completion of the field work, all data will be compiled and an analysis of variance performed to rank the factors in order of influence. With this knowledge it is hoped that it will be possible to predict which roads are likely to blowup, and what factors should be dealt with to prevent them from doing so.

Phase Two of the study combines field and laboratory studies. Measurements will be made of the thermal properties of concretes taken from the pavements included in the field study. These tests will be repeated on similar concrete samples made in the laboratory. Measurements will also be made of the thermal properties of the concrete aggregate. Other properties of the concrete that will be involved are its elastic modulus and strength. These will be determined for both

field and laboratory specimens. It will also be necessary to determine the composition of the field concrete, by both microscopical and chemical means. These results will be used to relate measured strains, temperatures, and moisture contents in the field to the nature of the materials that do or do not experience blowup difficulty.

Other laboratory data that probably will be needed to complete the picture of the blowup problem are the coefficients of permeability of the resurfacing, subgrade, base course, and shoulder materials and perhaps the solar radiation properties and thermal conductivities of the resurfacing.

A relationship between the measured strains and material properties will be determined for the test specimens under the effects of predetermined field conditions. This relationship will be checked by comparing it with the measurements taken in Phase One.

The results of Phase One and Phase Two will be used to correlate materials' properties to field conditions in Phase Three. By determining which properties affect the measured strain of Phase Two it should be possible to predict strains for any system of materials. A relationship will be determined to calculate an expected strain a given pavement system would undergo in the field. Comparing this result with the estimated allowable strains should determine if a pavement will be susceptible to blowing up.

BIBLIOGRAPHY

1. Lewis, D. W., "The Performance of Concrete Resurfacing in Indiana," *Proceedings*, Highway Research Board, December 1950.
2. Gotham, D. C. and Lord, G. W., "Concrete Resurfacing of Concrete Pavement in Various Stages of Deterioration," *Bulletin No. 87*, Highway Research Board, 1954.
3. Cook, John P. and Lewis, Russell M., "Evaluation of Pavement Joint and Crack Sealing Materials and Practices," *NCHRP Report 38*, 1967.
4. Gordinier, D. E. and Chamberlain, W. P., "Pressure Relief Joints for Rigid Pavements," *Research Report 68-12*, New York State Department of Transportation, 1968.
5. Graham, Malcolm D., "Summary of 1966 Rigid Pavement Blowup Survey," *Research Project No. 245*, New York State Department of Public Works, March 1967.
6. Hensley, M. J., "The Study of Pavement Blowups," *Research Project 10*, Arkansas State Highway Department, January 1966.
7. Illinois Division of Highways, "A Study of Blowups in Rigid Pavements in Illinois," *Research and Development Report 18*.

8. Stott, J. P. and Brook, K. M., "Report of a Visit to U.S.A. to Study Blowups in Concrete Roads," *RRL Report LR 128*, British Ministry of Transport, 1968.
9. "Repair of Concrete Blowups in Delaware," *Engineering News Record*, p. 432, September 1925.
10. Woods, K. B., Unpublished Report, Joint Highway Research Project, File No. 10-4-5, August 1942.
11. Gress, D. L., "Pavement Blowups and Resurfacing," *Joint Highway Research Project*, File No. 5-11-15, May 1971.
12. Sweet, H. S., "Research on Concrete Durability as Affected by Coarse Aggregate," *Joint Highway Research Project*, April 1949.
13. Walbeck, E. A. and Stromberg, F. J., "Statewide Rigid Pavement Survey," Bureau of Research, Maryland State Roads Commission, February 1969.
14. Bowers, D. G., "A Study of the Failures Occurring in the Concrete Pavement of the Connecticut Turnpike and Roads of Similar Design," *Connecticut State Highway Department*, June 1966.
15. Woods, K. B., Sweet, H. S., and Shelburne, T. E., "Pavement Blowups Correlated With Source of Coarse Aggregate," *Proceedings*, Highway Research Board, January 1946.
16. Sweet, H. S. and Woods, K. B., "Evaluation of Aggregate Performance in Pavement Concrete," *Joint Highway Research Project*, September 1948.
17. Sweet, H. S., "Research on Concrete Durability as Affected by Coarse Aggregate," *Joint Highway Research Project*, April 1949.
18. Goetz, W. H. and McLaughlin, J. F., "Performance Data for Some Bituminous Concrete Overlays in Indiana," *Proceedings*, Purdue University Road School, April 1957.