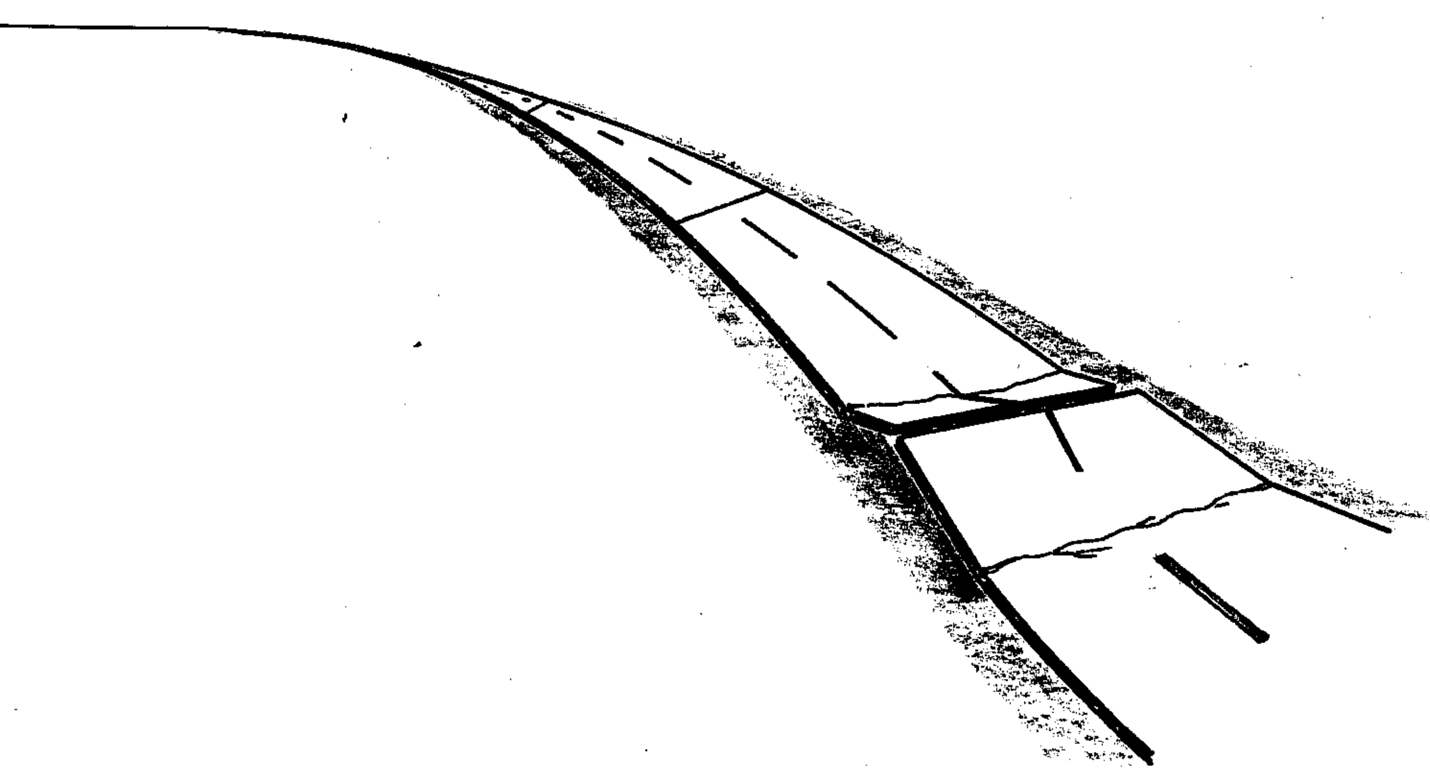
STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
DIVISION OF HIGHWAYS

A Study Of Blowups In Rigid Pavements In Illinois



RESEARCH AND DEVELOPMENT
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State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

A STUDY OF BLOWUPS IN RIGID PAVEMENTS IN ILLINOIS

Research Study IHR-7

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SUMMARY

It can be shown theoretically that compressive stresses caused in concrete pavements through rises in temperature within the normal range are not sufficient to cause failure even though the concrete is placed at the minimum temperatures consistent with good concreting practice and without provision for expansion space.

Theory notwithstanding, it has long been the experience that certain pavements are susceptible to "blowing up." The first indications of a blowup are shattering and spalling at a transverse joint or crack, accompanied by a slight rise of the abutting slabs. When the actual blowup occurs, the slab ends may rise several inches, sometimes very suddenly.

On a Statewide basis, blowups have not been found to occur with such frequency that they are in themselves a major factor in shortening pavement life, or a major drain on the maintenance budget. Nevertheless, they are of importance in that they can be a source of danger to inattentive or unwary motorists because of the sudden and often unexpected nature of their occurrence. They can cause serious disruption in the free movement of vehicles under high-volume traffic conditions, and they are sometimes found to be associated with other deterioration that shortens pavement life.

The study that is the subject of this report was undertaken to widen the knowledge of conditions surrounding the occurrence of blowups, with the hope that some of the information would be useful in developing means for reducing their number. The study was patterned after a similar investigation conducted in Indiana and reported in Volume 25 of the Highway Research Board Proceedings by Woods, Sweet and Shelburne under the title "Pavement Blowups Correlated with Source of Coarse Aggregate."

The Illinois study did not provide a positive correlation between blowups and the source of coarse aggregate as did the Indiana study. On the other hand, it did not establish that such a correlation does not exist. Certain pavement designs inclusive of jointing system were found seemingly to be associated with the frequency of blowups. The findings of others regarding general relationships between blowups and temperature and moisture conditions were corroborated. No other relationships were established. Earlier conclusions regarding the numerousness of the factors associated with blowups and the complexity of the interrelationships were confirmed. The study did not provide any "breakthrough" that would furnish new and positive methods of blowup control consistent with meeting other requirements for good practice.

STUDY PROCEDURE

This study originated in 1950 following the receipt of a report of an unusually great number of blowups needing maintenance in 1949. Procedures for conducting the study were developed and tested in 1950 and 1951. The accumulation of field data began in 1952 and extended through 1957.

An effort was made during the study to obtain information on all factors believed to have some association with blowups for all blowups occurring in State-maintained pavements during the period of study.

Form cards were supplied to all maintenance patrolmen for use in reporting blowups. A sample of the card is shown in Figure 1. It will be noted that only simple, readily obtainable information was asked to be recorded, with the hope that a minimum of inconvenience would encourage reporting. The completed cards were given by patrolmen to their supervisors to be forwarded through the district offices to the research project.

A second form sheet, as shown in Figure 2, was developed to obtain more detailed information about factors associated with blowups. It will be noted that most of the information required for completing this sheet is of a type available in district office files. One of these sheets was to be filled out for each blowup reported by maintenance patrolmen and submitted to the research project.

For the purpose of this study, a blowup was defined as having taken place when the removal of broken pavement and patching to the full depth of pavement was necessary, or where cutting was done to permit raised slabs to fall back into place on the subgrade. It was recognized that lesser disruptive movements that indicate excessive expansive pressure and which could be classified as blowups also occur; however, it was believed that the reporting of such occurrences could not be placed on a uniform basis when depending upon maintenance patrolmen to initiate the reports.

ANALYSIS OF DATA

All but a very few of the blowup reports that were received were concerned with blowups in rural or semirural areas. The few that were received for urban areas related mostly to older pavements with widening lanes and to municipal street designs. To remove this design variable, the reports received from urbanized District 10 were not included in the analysis. No blowups were reported for the urban expressway system which was relatively new and of short mileage at the time of the study.

A total of 2994 blowups were reported as having occurred in downstate Districts 1 through 9 during the six-year study period of 1952-57. Of these, 1162 were reported in 1952, with 1037 reported as having occurred in June of that year. Average daily temperature in June 1952 was 5.7° F above the long-term average for Illinois, and an excess of precipitation occurred.

A total of 11,420 miles of pavement made up of 3368 construction sections were included in the study. Blowups were reported to have occurred on 975 construction sections totaling 4960 miles of pavement.

A total of 141 blowups were reported to have occurred in some 3000 miles of bituminous-concrete resurfaced pavement.

PAVEMENT BLOWUP REPORT

Marked Route No.________________________

Maint. Section ________________________ Patrol No. ________________

Location of blowup: ________________ (Miles) ______________________________ (Direction) of

____
(Town or Other Definite Point)

Date of blowup____________________________Time of day________A.M. ________P.M.

Temperature at time of blowup____________________________________

Date of last rain before blowup__________________________________

Person reporting ____

14 Form RP 7206 (37140—5-56)

Figure 1. Pavement blowup report form

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways

REPORT OF BLOWUP

District______________
Marked Route____________
Built as:
______Route____________
Section______________
County______________
Maint. Section__________
Patrol______________

Location of blowup:__________________ of ____________________
direction town or other definite point

Year base course or pavement built__________ Cross section______________

Year surface course built__________ Thickness: Binder______ Surface______

Thickness granular base course________ Trenched_______Shoulder to shoulder______

Type and spacing of transverse joints__________________________________

Date of blowup__________________ Time of day __________ AM
__________ PM

Air temperature at time of blowup ________

Date of last rain before blowup________

MATERIAL DATA FOR BASE COURSE OR PAVEMENT:

Cement____

Fine aggregate source____________________________________

Coarse aggregate source__________________________________

Gravel__________ Stone__________

Figure 2. Form for reporting details associated with pavement blowup.

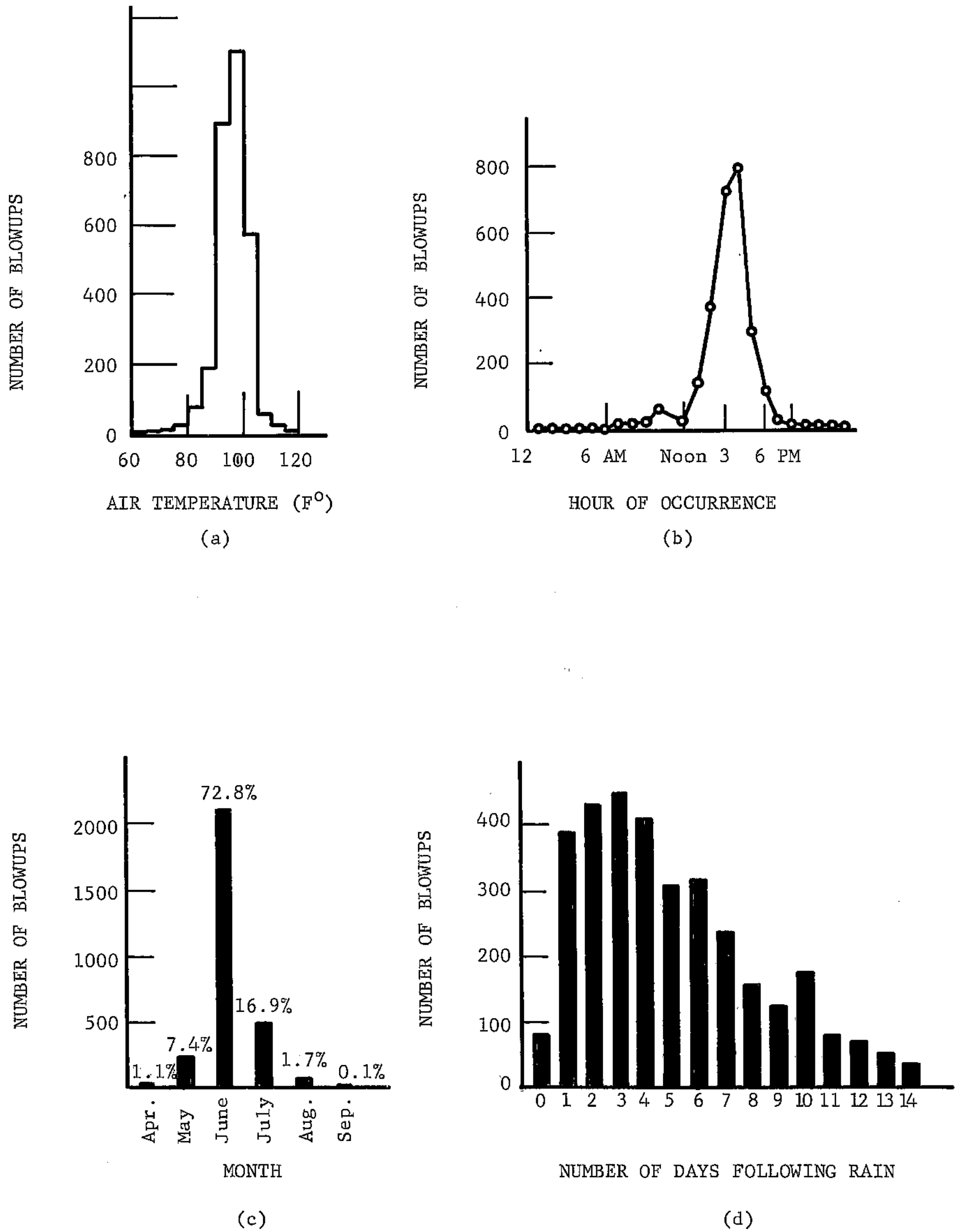


Figure 3. Climatic and time details associated with blowups

Climatic Conditions and Blowups

In addition to the date and time of day of each blowup, the air temperature at the time the blowup occurred and the date of the last rainfall preceding the blowup were recorded. The results of the analysis of the information reported on these items are summarized in Figure 3. It will be noted that the great majority of blowups occurred during the late spring and early summer months, between noon and 6:00 pm, at air temperatures of 90° F and over, and within a few days following a rain.

Seventy-three percent of the reported blowups occurred during the month of June, 17 percent during July; 7 percent in May; and all during the period of April through September.

Ninety percent of the blowups were reported to have occurred at air temperatures of 90° F and higher. The lowest temperature reported for a blowup was 60° F.

Seventy-five percent of the blowups were reported to have occurred within a week following a rainfall.

Eighty-five percent of the blowups were reported to have occurred between the hours of 1:00 pm and 6:00 pm.

The foregoing evidence is considered to confirm earlier experience that blowups take place during the presence of unfavorable combinations of high air temperature and high moisture conditions.

Pavement Design and Blowups

In recognition of the fact that blowups occur when a lack of expansion space exists, highway agencies have for many years experimented with and made use of a variety of concrete pavement designs that would provide expansion space in an effort to overcome the blowup problem. The Illinois Division of Highways is among those that have made numerous changes in design in the search for one to control blowups.

Unfortunately, designs that have shown the best promise in reducing blowups have not been capable of satisfying other criteria necessary for adequate overall performance. Even prior to the beginning of this study, an earlier trend toward frequent usage of expansion joints had been reversed and the limitation of expansion joint usage to only the most critical locations had become common. Structural weaknesses that developed at expansion joints and an apparent inability to retain an effective seal against the entrance of water and debris had proven discouraging to their use.

Pavements dating back at least to 1914 and to as recent as 1957 were involved in the present study. However, the great majority of the mileage was constructed during the 1920's and early 1930's at the time that Illinois was in the midst of its most intensive pavement construction program mileagewise.

In the very early years of concrete pavement construction in Illinois, little thought was given to the provision of expansion space. By 1923, when the earlier pavements had been in service for a sufficient length of time to develop blowups (usually at least four years), one of the highway districts began constructing four-inch open joints spaced at one-half-mile intervals. The use of the four-inch open joint soon became a Statewide standard, with the joint interval being decreased gradually. In 1926, the average spacing between the expansion joints was a little less than 1000 feet. In 1928, a spacing of not less than 800 feet nor more than 1000 feet was adopted as standard practice throughout the State.

The pavements during the period of use of the four-inch open joint were of thickened-edge cross section and contained single 3/4-inch diameter bars at each outer edge lapped to provide continuity. The edge bars were terminated at the expansion joints, leaving no mechanical load transfer between slabs. However, the slabs were thickened to the same dimensions as the outer edge at the expansion joints to compensate for the lack of load transfer.

The four-inch open joints may have postponed for a time the occurrence of blowups, but were found not to solve the problem. The widening of closed or nearly closed expansion joints by recutting to the original four-inch opening became a fairly common maintenance activity.

In 1932 the Illinois Division of Highways undertook to follow a nationwide trend toward the use of closely spaced expansion joints in combination with contraction joints. This use of closely spaced joints was encouraged by the Bureau of Public Roads.

In the years immediately following 1932, the Illinois standard design consisted of expansion joints spaced at 90-foot intervals with intermediate contraction joints spaced at 30-foot intervals. The expansion joints were all-metal and copper sealed to provide what was expected to be a leak-proof air chamber to meet expansion requirements. The contraction joints were full-depth metal plate with a copper seal at the top. Various kinds of load transfer devices were used at both the expansion and contraction joints. No distributed reinforcement was used with this design.

The metal joints were soon found to be incapable of preventing the entrance of water and uncompressible material, and showed other defects such as spalling and faulting. Experience also proved that the practice of installing the joints at 30-foot intervals did not control transverse cracking. Intermediate cracking soon developed in most of the 30-foot panels, and the cracks widened to the extent that the aggregate interlock was not sufficient to provide adequate load transfer. As the years passed, it was also found that expansion joints were not particularly effective in preventing blowups.

In a further effort to provide a pavement with greater structural integrity, a major change was made in design in 1937. The use of distributed steel reinforcement was adopted, expansion joints were spaced at 50-foot intervals, and contraction joints were eliminated. The new expansion joints were constructed 3/4 inch in width by providing premolded fillers of fiber, cork, rubber, or cork-rubber. The load transfer devices used in the earlier joints were retained.

Experience has shown this design to be more resistant than others to the occurrence of blowups. However, the fillers did not prove to be effective in preventing the entrance of water to the underlying soil, and the pavements of this design often presented a very rough riding surface caused by subgrade swell and frost heave at certain times of the year. Adequate load transfer across the joints was also found to be a problem.

In 1942, and during the subsequent years of World War II, the necessity for conserving steel required another change in design. The wartime design consisted of the elimination of the distributed steel reinforcement and a considerable reduction in the use of load transfer devices. Expansion joints were now spaced at 120-foot intervals with intermediate contraction joints spaced at 20-foot intervals. Not great mileage of this design was built, and experience offered nothing to indicate particular effectiveness in reducing blowups.

By 1944, steel again became available and the design was changed to include distributed steel reinforcement, and expansion joints spaced at 100-foot intervals without contraction joints. Mechanical load transfer was again provided at all joints.

While this design showed reasonably good performance in the short time that it was used, except for a built-in surface roughness at the joints, a nationwide trend toward the elimination of expansion joints because of structural and other deficiencies was followed by the Division of Highways. In 1946, the design was changed by the substitution of full-depth contraction joints for the expansion joints. The use of expansion joints was limited to special situations such as bridge approaches. This design was still being used at the conclusion of the blowup study in 1957.

The principal features of the major pavement designs included in the blowup study are outlined in Table 1.

To analyze the association of the several different pavement designs with blowups, the number of reported blowups per mile of pavement per year of construction was determined. Because of the usual practice of transitional changes in design,

TABLE 1.

DESIGN FEATURES OF ILLINOIS PAVEMENTS 1921 to 1957

Year Adopted	Note[1/]	Expansion Joints		Contraction Joints		Reinforcement	
		Type	Spacing	Type	Spacing	Type	Size
Prior to 1926	A	None	---	Construction joints only	---	Edge bars	3/4"
1926	B	4" open joints	800 to 1000 ft.	Construction joints only	---	Edge bars	3/4" or 7/8"
1932	C	Copper-sealed all metal air-chamber with load transfer	90 ft.	Copper-sealed metal with load transfer	30 ft.	None	---
1937	D	3/4" premolded fiber, cork, rubber or cork-rubber with load transfer	50 ft.	None	---	Distr. steel	55 lb per 100 sq ft
1941	E	3/4" premolded expansion joint	120 ft.	Dummy	20 ft.	None	---
1944	F	3/4" premolded bituminous material, premolded bituminous fiber, cypress or redwood	100 ft.	None	---	Distr. steel	78 lb per 100 sq ft
1946	G	None	---	Metal plate with load transfer	100 ft.	Distr. steel	78 lb per 100 sq ft

Note[1/] Designation used in Figure 4.

some difficulty was experienced in assigning blowups to designs during transitional years. However, the assignments that were made are considered adequate for the intended purpose. The results of the analysis are shown in Figure 4.

It will be noted from Figure 4 that during the period of study the blowups were reported most frequently for the pavements constructed prior to 1938. Pavement designs of the years prior to 1938 included those without expansion joints, those with the four-inch open expansion joints, and those with expansion joints at 90-foot intervals. None of these pavements contained distributed steel reinforcement.

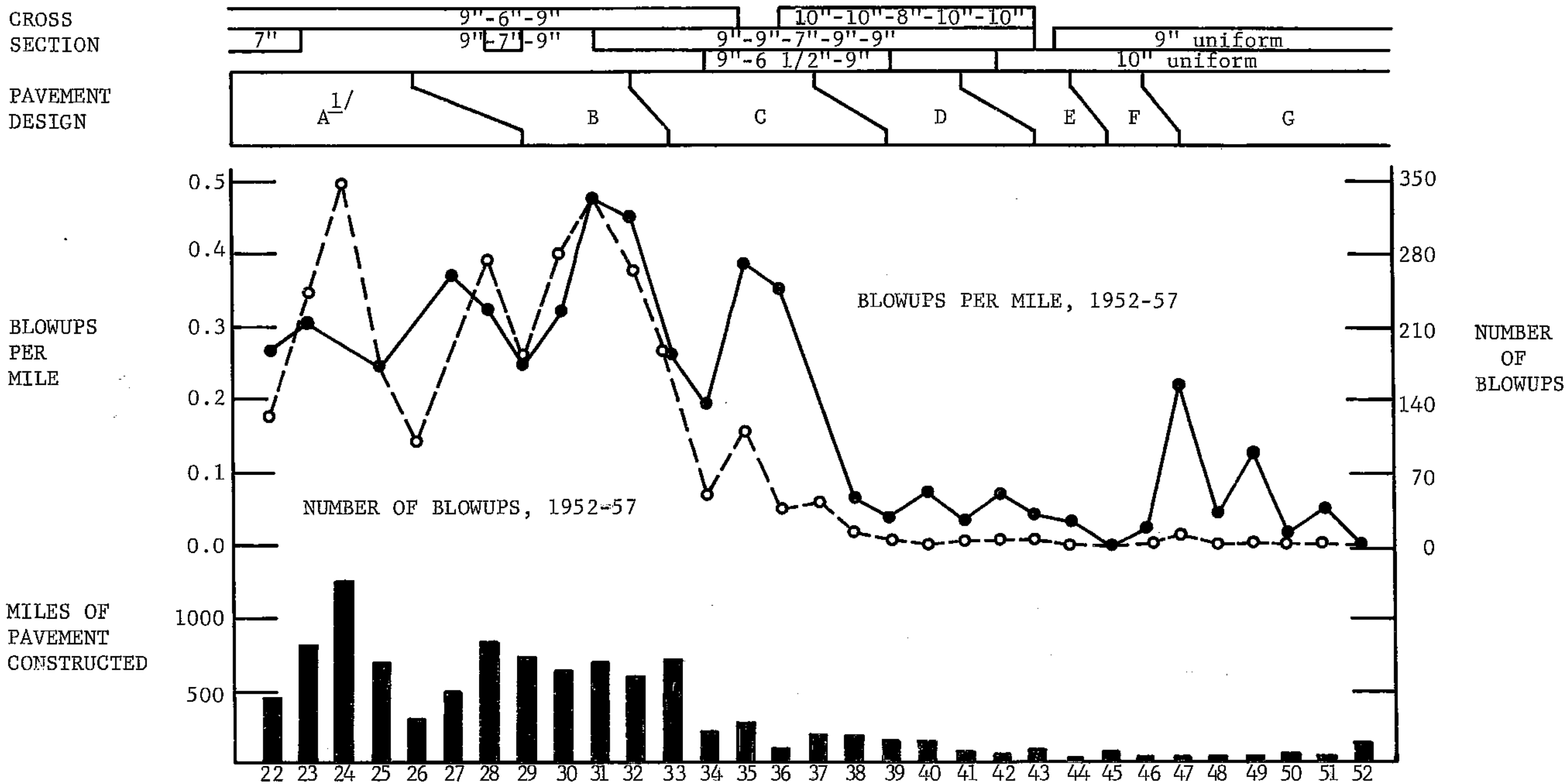
Pavements showing better performance are those constructed during the years of 1938 through 1941, containing expansion joints at 50-foot intervals and distributed steel reinforcement, and those constructed during the period of 1944 to 1946 with expansion joints at 100-foot intervals and distributed steel reinforcement. The pavements constructed without steel and with expansion joints at 120-foot intervals during the wartime years were showing similarly good performance at the time of the study; however, these pavements were found to be structurally inferior and offered no encouragement for further use.

Finally, the design that was current during the period of the study was found not to be especially resistant to blowups.

Concrete Materials and Blowups

On the basis of the Indiana study mentioned previously, it was presumed prior to undertaking the present study that a positive association would be found between source of coarse aggregates and blowup frequency. This did not prove to be the case. No evidence was found to indicate either marked superiority or inferiority of any of the coarse aggregates with respect to resistance to blowups.

Sources of all materials, including coarse aggregates, used in pavements during the construction period under consideration, were determined from construction and



1/ See Table 1 for details of pavement design

Figure 4. Blowup frequency in relation to pavement design

material records. The exercise of considerable judgment was required because of changes in ownership and identifying names of many sources through the years, and a frequent use of the same kind of material from two or more sources on single construction projects.

Within the limitations of the available information, 222 individual sources of coarse aggregates were identified for the pavements of the study. Blowups were reported for pavements with coarse aggregates from 132 of these sources. Many of the coarse aggregates were used in mileages of pavement too short for consideration in a study of this type. No coarse aggregate showed consistently good or consistently poor performance in relation to blowup frequency. For each of the four principal sources of coarse aggregate, which accounted for a third of the reported blowups, a slightly greater mileage of pavement was in construction sections for which no blowups were reported.

What has been said for coarse aggregates may similarly be said for fine aggregate sources and cement sources as related to blowup frequency. No positive relationships were determined, and no consistently good or bad performances could be determined.

Subgrade Soils, Granular Subbases and Blowups

With the information at hand, no relationships between blowup frequency and subgrade soil type, and between blowup frequency and the use or nonuse of granular subbase, were observable. If such relationships exist, they were not detectable in the present study.

DISCUSSION

The procedures that were adopted for conducting the blowup study that is the subject of this report were designed to detect only the strongest of associations that might exist between blowup frequency and the variables selected as having a probable influence on blowups. While pointing out the single association involving relatively good performance of pavements containing expansion joints at frequent intervals in combination with distributed steel reinforcement as compared with other pavement designs involved in the study, the study did not provide sufficient information to suggest the elimination from further consideration any of the other variables thought to influence the frequency of blowups.

The method of study depended heavily on the voluntary cooperation of people untrained in research and not knowledgeable in highway engineering for the full and accurate reporting of field observations. This placed certain limitations on the amount and type of information that could be obtained. It has become evident from this study that various items of information that might relate to the frequency of blowups, such as terrain, construction aberrations, pavement failures of other types that might preclude the formation of blowups, nonuniform policies in the cutting of relief expansion joints, and others, which could not be detected by the field people involved in the study, should not be ignored where a higher degree of precision in detecting relationships of items associated with blowup frequency is desired.

RESULTS

The Illinois blowup study, covering a six-year period during which 2994 blowups were recorded in 11,420 miles of pavement constructed as 3368 construction sections principally in rural areas, showed:

(1) Seventy-three percent of blowups taking place in the month of June; 17 percent in July; 7 percent in May; and all between the months April and September inclusive.

(2) Ninety percent of all blowups taking place at 90° F and higher; with the lowest temperature recorded at time of blowup being 60° F.

(3) Seventy-five percent of all blowups taking place within a week following a rainfall.

(4) Eighty-five percent of all blowups taking place between the hours of 1:00 pm and 6:00 pm.

A total of 141 blowups were reported as having taken place in 2500 to 3000 miles of bituminous concrete resurfaced pavement during the six-year study period.

Pavements with expansion joints at relatively close intervals (50 feet and 100 feet), in combination with distributed steel reinforcement, showed a lower blowup frequency than pavements with a variety of expansion joint spacings ranging from short to long but without distributed steel reinforcement, and pavements with distributed steel reinforcement but with contraction joints only.

No associations were detected between blowup frequency and coarse aggregate source, fine aggregate source, cement source, subgrade soil type, and use or nonuse of granular subbase. On the other hand, none of these items can be exonerated from further consideration as a result of the study.

Although expansion joints in combination with distributed steel reinforcement appear to have some effect in reducing blowup frequency, past experience with poor structural performance and an inability to retain seal against the entry of water are not encouraging to their use.

No recommendations for changes in design or material usage are considered appropriate on the basis of the blowup study.

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