FIELD OBSERVATIONS ON EFFECTS OF JOINTS ON CRACKING AND OTHER DETERIORATION IN CONCRETE PAVEMENTS

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SYNOPSIS

This report gives the data on the relative amounts of transverse cracking and blowups experienced in concrete pavements constructed with and without expansion joints and with varying spacings of transverse contraction joints. The data were collected by detailed surveys on some 450 mi. of concrete pavement selected from a total of 4,000 mi so as to be as nearly comparable as to age and design as was possible

Pavements constructed from chert gravel and crushed limestone coarse aggregate both reinforced and unreinforced were included

In addition to the data on cracking and blowups, information was collected and reported as to the amounts of other surface defects and deterioration present, but not directly related to the use of joints.

It was found that up to the age of the pavements studied the use of contraction joints in unreinforced chert aggregate pavements at 40-ft intervals was accompanied by a reduction in both transverse cracks and blowups and that a similar result was secured on both reinforced and unreinforced limestone aggregate pavements by contraction joints at 80-ft. spacing.

In general it was found that increase in the number of expansion joints in all types of pavements surveyed resulted in more transverse cracks without much advantage due to elimination of blowups.

The use of mesh reinforcement was accompanied by a substantial decrease in cracking.

From these findings the authors conclude: that under Missouri conditions the use of contraction joints at suitable intervals is very beneficial, that expansion joints are not necessary or desirable with limestone aggregates, but that some provision for expansion is considered necessary with the chert gravel pavements in order to control blowups.

The Missouri Highway Department has been studying for a number of years the effects of varying intervals of expansion and contraction joints in concrete pavements. These studies have consisted of detailed condition surveys, designed to discover the actual effects on the service behavior of full scale pavements, and have included considerable mileage of pavements having no expansion or contraction joints, contraction joints alone, expansion joints without additional contraction joints and, finally, varying combinations of both types of joints.

At the Annual Meeting of the American Association of State Highway Officials held at Boston, Massachusetts, in 1937, a paper was given, describing some of the trends developed up to that time in pavements about 7 years old and including some older pavements of certain types. This paper was published together with a brief summary table showing some of the results of the comparisons made.[1]

The trends indicated by those surveys did not at that time agree with some of the popular conceptions of the design theory involved and it was feared that the moderate age of the pavements compared might be responsible for some unreliable indications if interpreted in terms of future pavement ages.

[1] American Highways, October, 1937, Vol. 16, No. 4.

These surveys have been repeated at later ages, and, since the original trends have not reversed, it appears that the data collected should be published for the information of others interested in the subject.

This report is designed to make these data on joints available in as concise a manner as possible with some explanatory and conjectural discussion but without any attempt at a discussion of the fundamental theories involved. Since the original production of these data, several cooperative investigations have been started by highway departments and the Public Roads Administration which, when finally evaluated, should go far toward forming a satisfactory design theory. The present objective is to show what has actually happened in this State under the particular conditions of climate, materials, construction and subgrade support that exist here without regard to how nearly the behavior follows present hypotheses or experiences in other localities.

The State highway system in Missouri includes about 4,000 miles of concrete pavement of various designs built with various materials since 1920. In general, with the exception of the pavement width, it has been the practice to adopt a uniform, standard pavement design regardless of location, type of subgrade, traffic or other conditions. As improvements in materials and design were indicated during the evolution of the modern pavement, the standard specifications were changed to incorporate the various improvements or eliminate the objectionable features. Consequently, there is available for study and comparison considerable mileage of pavements of various designs and ages built with different materials.

A summary of the principal features of design that were used in construction is given in Table 1 which shows the various types of pavements available for study and comparison. In addition to the pavements constructed according to the designs tabulated, there were a few special designs built for experimental purposes. These will be described and discussed individually in connection with the specific points which they demonstrate.

For some time prior to 1937 it had been evident that transverse expansion joints were not functioning as intended. It was apparent that the anticipated degree of transverse crack control had not been attained and there was even evidence in some cases that the use of the joints was causing increased cracking. Consequently, in 1937 a condition survey was made to investigate the results obtained with transverse joints of various types and spacings. To corroborate the observations of this survey and to investigate the results after additional service, another condition survey was made two years later on the same pavements. The results of these two surveys form the basis of our information on pavements built with joints of various types and spacings.

When the investigation was started in 1937 the oldest pavements available for study in which transverse joints had been used were about seven years old, constructed in 1930. Since 1930 no pavements had been built without transverse joints of some type. Therefore, in order to obtain observations on pavements of comparable age built without joints, it was necessary to use data from a previous condition survey. For this purpose observations obtained in 1930 from a condition survey made in co-operation with the Portland Cement Association were taken. This survey covered all pavements in the State constructed prior to 1928 and included over 1,500 miles of concrete pavements. The pavements included in the 1937 and 1939 surveys were selected to give the maximum available mileage representative of the various types of construction and total about 450 miles.

MATERIALS

In this State the great preponderance of pavements have been built with either

TABLE 1

SUMMARY OF VARIOUS TYPE OF PAVEMENTS AVAILABLE FOR COMPARISON

Type No	Pavement width	Cross section Bates type	Transverse joints		Distributed reinforcement	Other steel reinforcements		Load transfer joints	Year design adopted as standard
			Type	Spacing		Longitudinal	Transverse		
	ft								
C-1 and L-1	18	9-6-9 in.	None		None	¾ in round smooth bars 4 in from each edge	None		1923
L-2	20	9-6-9 in 9 in for 2 ft in from edges	None		Continuous mesh 50 lb per 100 sq ft	None	None		1929
C-3	20	9-6-9 in 2 ft of 9 in.	Contraction	20 ft in cuts 40 ft on fills	None	¾ in round smooth bars, 4 in from each edge	None	None	1930
L-3	20	9-6-9 in 2 ft. of 9 in	Contraction	40 ft in cuts 80 ft. on fills	None	¾ in round smooth bars, 4 in from each edge	None	None	1930
C-4 and L-4	20	9-6-9 in. 2 ft of 9 in	Alternate expansion and contraction	40 ft	None	¾ in round smooth bars, 4 in from each edge and at 5 in each side center line	¾ in round by 9 ft. 6 in smooth bars each side of joint	¾ in. round smooth bar dowels spaced 2 ft. 6 in.	1931
C-5 and L-5	20	9-7-9 in 2 ft of 9 in.	Alternate expansion and contraction	40 ft	Wire mesh generally 44 lbs. per 100 sq ft.—a few cases of 36 lbs. per 100 sq ft	None on some—or ¾ in round smooth bars 5 in each side of center line on others	None	¾ in round smooth bar dowels spaced 2 ft 6 in.	1931–32
C-5B and L-5B	20	9-7-9 in 2 ft. of 9 in	Expansion	40 ft	Wire mesh 44 lbs. per 100 sq ft or bar mat—51½ lb per 100 sq ft	¾ in round smooth bars 5 in each side of center line	None	None	1932
L-6	20	9-7-9 in 2 ft of 9 in	Contraction	40 ft in cuts 80 ft on fills	Wire mesh 36 lbs per 100 sq ft	None	None	None	1930

crushed limestone or chert gravel. Fundamental differences in the concrete made from these two aggregates have long been recognized. All condition surveys have exhibited evidences of these differences until it has become generally accepted that transverse cracks and blowups occur much more frequently in pavements built with chert aggregate than in comparable pavements built with limestone aggregate. Laboratory studies of the properties of concretes made from these two aggregates have confirmed this difference, explainable, in some degree at least, by the higher thermal coefficients of the chert aggregates. For this reason, the pavements have been grouped into two general classifications according to the type of coarse aggregate used, and each group has been studied separately. In the data and discussion, Type C pavements designate those built with chert aggregate and Type L pavements indicate that limestone was used as coarse aggregate.

PROCEDURE

From the project construction records a representative number of pavements of each type were selected for observation. Careful consideration was given to each project so that those selected would be as representative as possible of the average pavement of its type. The pavements selected were distributed throughout the State and the entire system sampled so as to give typical pavements of each classification. To represent pavement without joints or mesh, Type 1 projects were selected, the average transverse crack interval of which most closely approximated the average for the entire State in the 1930 survey For the other types of construction projects were chosen which were comparable, in so far as possible, with those of the first type. No pavements were included which were found to be irregular as to materials, subgrade, conditions, construction procedure or any other details.

Before starting the field observations, forms were prepared on which to record the survey data. On these forms were itemized in the office, design features, construction dates and details, materials and description of the project limits so that the pavement could be conveniently located in the field. Spaces were provided for recording the following observations:

A. For Pavements Without Joints
1. Number of full transverse cracks (extending from edge to edge)
2. Number of contraction joints
3. Number of half transverse cracks (extending from one edge to centerline)
4. Number of blowups
5. Number of crowfoot cracks
6. Number and area of patches and probable cause
7. Number and type of corner breaks
8. Number and length of longitudinal cracks
9. Number and size of broken and depressed areas
10. Number and surface blemishes of various types; scaling, spalling and raveling
11. Number and size of areas affected by map cracking
12. Exceptions: areas of fill settlement, mud-jacked areas
13. Remarks and special notes

B For Pavements With Joints
1. Total number of slabs of given length (between joints)
2. Number of slabs with one full transverse crack
3. Number of slabs with cracks less than one full crack
4. Number of slabs with more than one full crack
5. Number of blowups
6. Number of crowfoot cracks
7. Number and area of patches and probable cause

8. Number and type of corner breaks
9. Number and length of longitudinal cracks
10. Number and size of broken and depressed areas
11. Number of surface blemishes of various types; scaling, spalling and raveling
12. Number and size of areas affected by map cracking
13. Exceptions: areas of fill settlement, mud-jacked areas
14. Slabs excluded because of odd length or unusual conditions
15. Remarks and special notes

As mentioned previously, in order to obtain information relative to the condition of comparable pavements without joints or mesh, it was necessary to use data from the 1930 condition survey. These data for the projects selected were used as obtained from the 1930 records but each of these projects was resurveyed in 1937 and 1939. In 1930 the data were obtained by three experienced observers driving along the pavement at a speed of about five miles per hour. When the pavements were resurveyed in 1937 and 1939, two of the same observers participated in the work and the same procedure was followed except that many of the observations were made on foot rather than from a car. The 1937 and 1939 surveys were made by two parties each consisting of either two or three qualified, experienced observers. In surveying pavements without joints, two observers usually performed the work on foot; for pavements with joints, three men generally were used and the observations obtained by driving slowly along the pavement in a car, each observer watching for and counting certain defects assigned to him. All reinforced pavements were inspected on foot so as not to miss any fine cracks that might be held tightly closed by the mesh.

After obtaining the field notes and tallying the various defects, the following computations were made for each project or section of pavement surveyed:

A. For Pavements Without Joints
1. Average uncracked slab length
2. Transverse cracks and construction joints per 1,000 lin. ft of pavement
3. Average number of blowups per mile
4. Average number of corner breaks per mile
5. Number of cases and total area of broken and depressed pavement
6. Number and total area of patches
7. Number of cases and total areas affected by map cracking

B. For Pavements With Transverse Joints
1. Cracks and joints per 1,000 lin. ft of pavement
2. Percentage of slabs cracked
3. Average number of blowups per mile
4. Average number of corner breaks per mile
5. Number of cases and total area of broken and depressed pavement
6 Number and total area of patches
7. Number of cases and total area affected by map cracking

DATA AND DISCUSSION

It should be borne in mind that this is a report of condition surveys of pavements all of which are still in service and some of which have served but a small proportion of their expected life. It is in reality a progress report and subsequent observations will be required to confirm the findings of these surveys

The authors know of no means for accurately predicting the useful service lives of pavements based on condition surveys at early ages but in a general way the

stages through which pavements disintegrate are known and certain manifestations, evident at early ages, can be used to indicate the relative merits of various features of pavement design. It is obvious that any pavement which has numerous transverse cracks or blowups, even at an early age, is inferior to a comparable pavement that has a fewer number of these defects. Therefore, any feature of design that will tend to prevent cracking or blowups at early ages is desirable even though this beneficial effect is not visible at later ages when both pavements may have developed approximately the same percentage of defects.

In the normal course of concrete pavement deterioration and wearing out, transverse cracks, which are failures due to tension, flexure or compression, are undoubtedly points of weakness at which forces of destruction may begin action. Transverse cracks and blowups are unsightly, difficult to maintain and are generally considered objectionable. A universal objective in pavement design and construction is to eliminate as many of them as practicable. This is generally accomplished or attempted by means of transverse joints spaced at various intervals. Varying degrees of success have been attained with different types and spacings of these joints.

The primary purpose of this survey was to investigate the relative effectiveness of various types and spacings of transverse joints in controlling transverse cracking and eliminating blowups. Consequently, the counts of transverse cracks and blowups are considered the principal criteria and the observations of other defects regarded as of secondary interest. The later data are included in the tabulations of this study and in some cases are referred to for illustrating certain points but a complete analysis of all these observations is not within the scope of this report. Therefore, in the data and discussion that follow, the various pavements are compared, in general, on the basis of their success in controlling transverse cracking and in preventing blowups

Tables 8, 9 and 10 summarize the average survey results for each type of construction and coarse aggregate. In the discussion that follows, these averages will be used as indicative of the type of pavement under consideration. (*Complete data for each individual survey section are available for inspection at the office of the Highway Research Board.*)

Chert Aggregate vs. Limestone Aggregate Pavements

As previously stated, it has long been evident from observations that both transverse cracking and blowups are much more numerous in pavements built with chert aggregate than in comparable pavements built with crushed limestone. The data of this survey also show this difference. The comparisons in Table 2 are taken from the summary Tables 8 and 9 to illustrate the difference between limestone and chert pavements built without joints or reinforcement.

These comparisons show that at 5 years of age pavements built with limestone had developed 10.5 cracks per 1,000 ft. or an average crack interval of 95.2 ft. while comparable chert aggregate pavements had 26.1 cracks per 1,000 ft. or a crack interval of only 38.3 ft. This advantage persisted as the pavements grew older, at 14 years of age the limestone pavements had an average crack interval of 61.3 ft (16.3 cracks per 1,000 ft.) whereas the chert pavements had cracks at an average interval of 26.2 ft. (38.1 cracks per 1,000 ft.). This shows that on the average unreinforced pavements without joints built with chert aggregate develop in 14 years over twice as many cracks as have occurred at the same age in comparable pavements built with limestone aggregate.

The comparisons of blowups in pavements built with the two types of aggregates show that in unreinforced chert

aggregate pavement without joints there are 3.9 more blowups per mile at 14 years than in comparable limestone pavements. In other words, in the limestone pavements there is on the average one blowup every 4,800 ft. but in the comparable chert pavements blowups have occurred at the rate of one every 1,055 ft It is also noticeable that all of the chert pavements developed blowups while 3 of the 13 projects built with limestone had no blowups in 14 years.

one every 10 miles in 9 years, while in comparable chert pavements a blowup occurred once in every 2 miles.

Discussion of the relative cracking and number of blowups on chert aggregate pavements as compared to limestone pavements could be extended to considerable length but a study of the relative merits of the two aggregates is not apropos to the subject of the effect of transverse joints on cracking. The comparisons are given merely to show that the two aggre-

TABLE 2

TRANSVERSE CRACKING IN CHERT AGGREGATE VS. LIMESTONE AGGREGATE PAVEMENTS WITHOUT JOINTS OR REINFORCEMENT

Age years	Chert aggregate	Limestone aggregate	Difference
	Cracks per 1000 ft	Cracks per 1000 ft	Cracks per 1000 ft
5	26 1	10 5	15 6
11½	34 6	14 5	20 1
14	38 1	16 3	21 8

BLOWUPS IN CHERT AGGREGATE VS LIMESTONE AGGREGATE PAVEMENTS WITHOUT JOINTS OR REINFORCEMENT

Age years	Chert aggregate		Limestone aggregate		Difference Blowups per mi
	Blowups per mi	No of proj with blowups	Blowups per mi	No of proj with blowups	
5	0 3	7 of 14	0 01	1 of 13	0 29
11½	4 3	14 of 14	0 40	9 of 13	3 90
14	5 0	14 of 14	1 10	10 of 13	3 90

A similar relationship is seen in comparisons of the two types of aggregates when used in pavements with joints. The averages in Table 3 are extracted from the summary tables (8, 9) to show that wherever the two aggregates were used in comparable pavements the chert aggregate pavements invariably developed more cracking than the limestone pavements. No blowups occurred in any of the pavements built with expansion joints but in the Type 3 pavements with contraction joints only, the limestone pavements developed blowups on the average of only

gates produce fundamentally different pavements which must be considered separately in studying the effects of joints on cracking and blowups. The difference in cracking between pavements built with the two aggregates may become less as they grow older but it is apparent that there is a distinct difference at the ages at which it is necessary to make the comparisons for this study. Consequently, pavements built with limestone aggregate have been tabulated and discussed separately from those built with chert aggregates.

Comparisons of Pavements of Different Ages

In a study such as this, of numerous pavements built at different times, it is not possible to survey the pavements all at the same age. As seen in the summary tables, the average ages of the different types of pavements to be compared vary from 4½ to 6½ years at the time of the first survey and from 7½ to 9 years at the time of the second survey.

In order to compare the various types of pavements on the basis of the results shown by these averages, one of two courses must be followed; i.e., the difference in age must be disregarded and the values used as recorded or the values must be interpolated so as to bring them to the same age. It might seem that the values obtained by averaging observations on a group of pavements as was done in these surveys are not sufficiently definite to warrant accepting them as mathematical identities and interpolating between them. Only two sets of observations at an interval of about 2½ years were made in the case of the pavements with joints and those may not be enough to show the trend with respect to age. However, when the average value of cracks and joints per 1,000 ft. for both pavements with and without joints are compared, it can be seen that the trends appear to be fairly uniform for the various types of designs. A study of the averages indicates that straight line interpolation to bring the data for the various types of pavements to the same age is probably justifiable Even though the actual shapes of the curves between any two of the plotted values

TABLE 3

COMPARISONS OF TRANSVERSE CRACKING IN CHERT AGGREGATE AND LIMESTONE PAVEMENTS OF VARIOUS TYPES

Approximate age	Pavement type	Joint spacing ft	Chert aggregate		Limestone aggregate		Difference	
			Cracks per 1000 ft	Blowups per mile	Cracks per 1000 ft	Blowups per mile	Cracks per 1000 ft	Blowups per mile
CONTRACTION JOINTS AT 40 FT —NO MESH								
6½	3	40	9 0	0 2	4 6	0 1	4 4	0 1
9	3	40	10 9	0 5	7 4	0 1	3 5	0 4
ALTERNATE EXPANSION AND CONTRACTION JOINTS AT 40 FT —NO MESH								
5½	4	40	20 2	0	8 1	0	12 1	0
8½	4	40	21 9	0	12 5	0	9 4	0
ALTERNATE EXPANSION AND CONTRACTION JOINTS AT 40 FT.—MESH								
5	5	40	8 0	0	6 9	0	1 1	0
8	5	40	10 5	0	9 2	0	1 3	0
EXPANSION JOINTS AT 40 FT.—MESH OR BAR MAT								
5	5-B	40	16 3	0	11 0	0	5 3	0
7½	5-B	40	18 5	0	12 3	0	6 2	0

may not be apparent and the interpolated values may be questioned quantitatively, it appears from consideration of the relative trends that interpolation would be satisfactory for comparing the various pavements on the basis of the average cracks and joints per 1,000 ft., blowups per mile and percentage of slabs cracked.

On this premise, a number of comparisons have been made to show the effects at the same age of various types and spacings of transverse joints when used with and without distributed reinforcement in pavements built with stone and gravel aggregate. These comparisons are shown in tabular form in Figures 1, 2, 3, 4, 5, 6 and 7. The same comparisons are given in Tables 5, 6 and 7 but in the latter tables no interpolation has been made and the comparisons were made on the basis that the pavements at time of survey were essentially the same age. In the opinion of the observers, the comparisons tabulated in Figures 1 to 7 with interpolated values are more truly indicative than those given in Tables 5, 6 and 7.

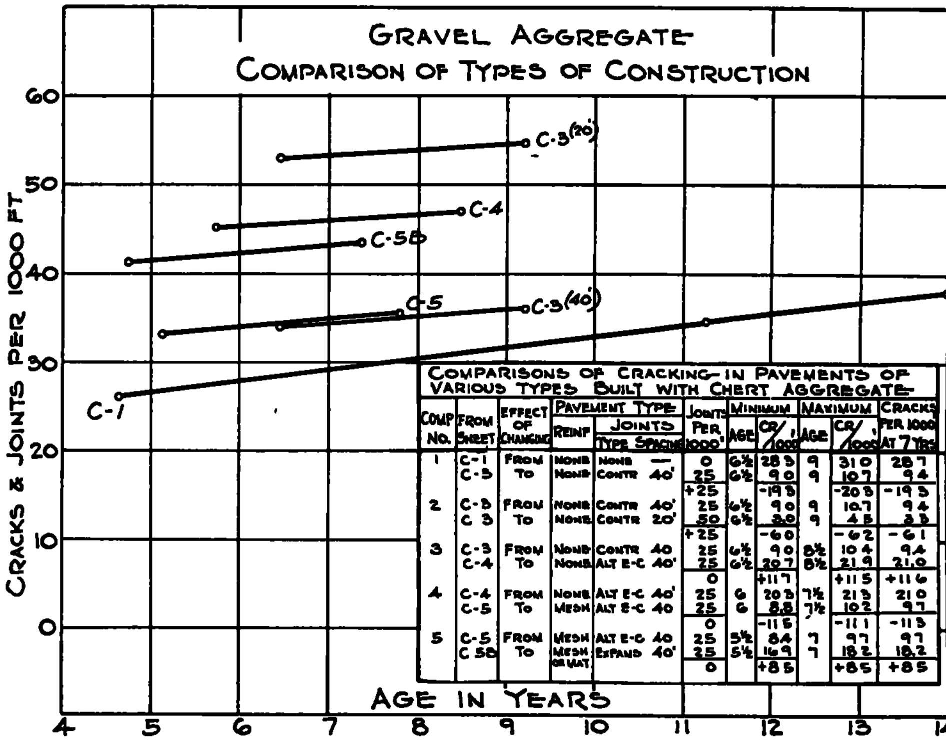
In Figures 1, 2, 3, 4 and 5, for each change in type, comparisons are shown at three ages: (1) the minimum age at which comparisons can be made, (2) the maximum age at which they can be compared, and (3) at 7 years, this being the age at which interpolations can be made to permit comparisons for all types. Study of these data will indicate numerous deductions. The most important of these, which in the opinion of the observers reflect influences that are worthy of consideration, will be pointed out in the following discussion:

Effect of Introduction of Contraction Joints

Reference to the tables of comparisons between Type 1 and Type 3 pavements on the figures shows that the use of contraction joints results in a reduction in the number of transverse cracks. This is shown in comparisons No. 1 and 2 of Figure 1 for chert aggregate and in comparisons No. 1 and 3 of Figure 2 for limestone aggregate pavements. In no case is the number of cracks eliminated equal to the number of joints introduced; but, since for numerous reasons a joint is considered much more desirable than a natural crack, each joint can eliminate less than one crack and still be advantageous As shown in Figure 1, comparison 1, introduction of 25 joints per 1,000 ft. (a 40-ft. interval) resulted in eliminating 19.3 cracks at the age of 7 years in unreinforced chert aggregate pavements The introduction of an additional 25 joints per 1,000 ft. (a joint spacing of 20 ft.) eliminated an additional 6 1 cracks per 1,000 ft. at 7 years as shown in comparison 2. This same joint spacing (20 ft.) on a special group of projects all built with chert from one source (Gasconade River) and without mesh had a similar effect in that the introduction of the additional 25 joints per 1,000 ft. resulted in the elimination of 7 cracks at the age of 8 years. This is shown in comparison 1 of Figure 3.

In the case of limestone pavements without mesh, the introduction of 12 5 joints per 1,000 ft. (an 80-ft. joint interval) resulted in the elimination of 6 6 cracks per 1,000 ft. at the age of 7 years. In the case of reinforced limestone pavements (comparison 3) the use of joints at 80-ft. intervals resulted in the elimination of 9.0 cracks per 1,000 ft. at 7 years of age. When an additional 12 5 joints per 1,000 ft. were introduced in the limestone pavements (a joint spacing of 40 ft.) there was practically no change in the cracking in either the unreinforced or the reinforced pavement as shown in comparisons 2 and 4 of Figure 2.

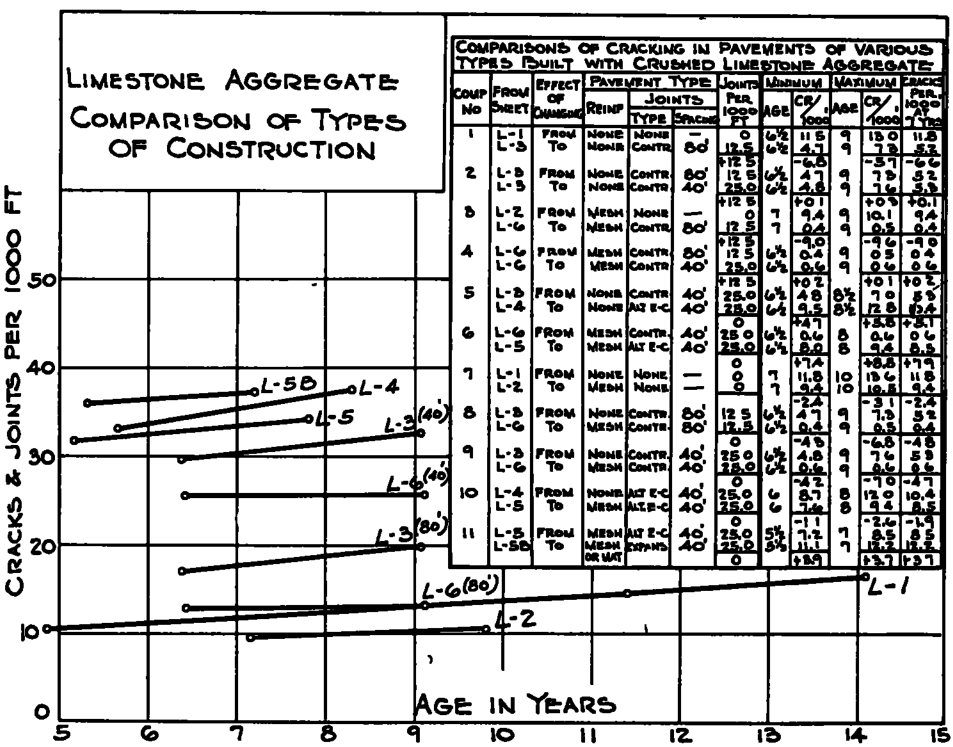
The degree of crack control obtained with the use of contraction joints is further illustrated in Figure 5 by comparisons of percentage of slabs that cracked. As shown in the table in this



Comparisons of Cracking in Pavements of Various Types Built with Chert Aggregate

Comp No.	From Sheet	Effect of Changing	Pavement Type: Reinf	Joints: Type	Joints: Spacing	Joints per 1000'	Minimum: Age	Minimum: Cr/1000'	Maximum: Age	Maximum: Cr/1000'	Cracks per 1000' at 7 Yrs
1	C-1	From	None	None	—	0	6½	28 3	9	31 0	28 7
	C-3	To	None	Contr	40'	25	6½	9 0	9	10 7	9 4
						+25		-19 3		-20 3	-19 3
2	C-3	From	None	Contr	40'	25	6½	9 0	9	10.7	9 4
	C 3	To	None	Contr	20'	50	6½	3.0	9	4 5	3 3
						+25		-6 0		-6 2	-6 1
3	C-3	From	None	Contr	40	25	6½	9 0	8½	10 4	9.4
	C-4	To	None	Alt E-C	40'	25	6½	20 7	8½	21 9	21.0
						0		+11 7		+11 5	+11 6
4	C-4	From	None	Alt E-C	40'	25	6	20 3	7½	21 3	21 0
	C-5	To	Mesh	Alt E-C	40	25	6	8.8	7½	10 2	9 7
						0		-11 5		-11 1	-11 3
5	C-5	From	Mesh	Alt E-C	40	25	5½	8 4	7	9 7	9 7
	C 5B	To	Mesh or Wat	Expand	40'	25	5½	16 9	7	18 2	18.2
						0		+8 5		+8 5	+8 5

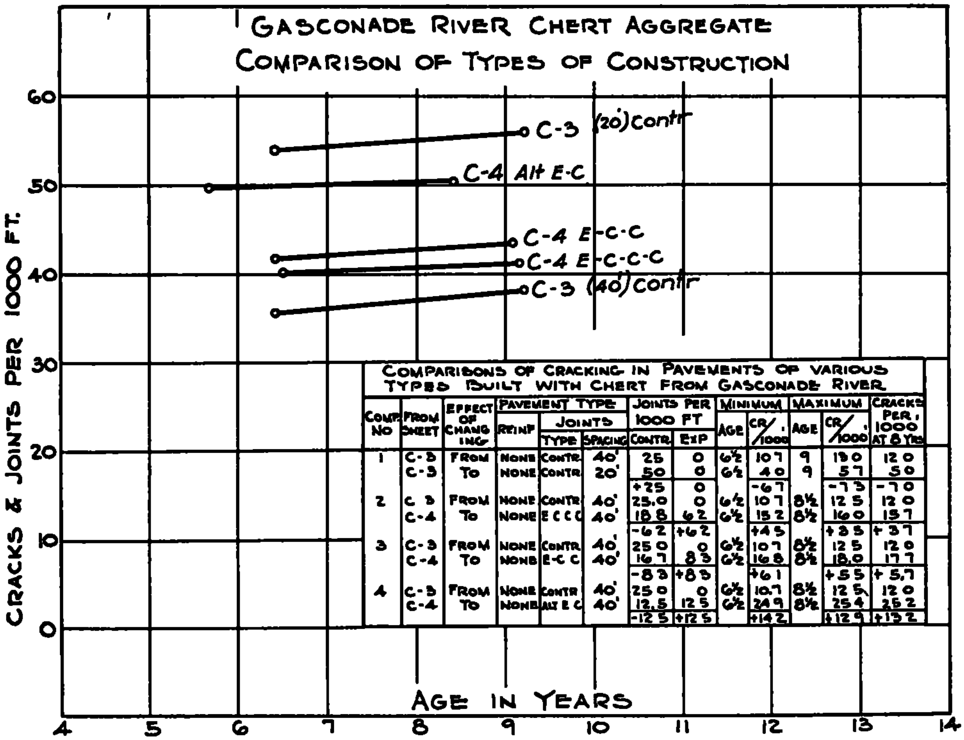
Figure 1



Comparisons of Cracking in Pavements of Various Types Built with Crushed Limestone Aggregate

Comp No	From Sheet	Effect of Changing	Pavement Type: Reinf	Joints: Type	Joints: Spacing	Joints per 1000 Ft	Minimum: Age	Minimum: Cr/1000'	Maximum: Age	Maximum: Cr/1000'	Cracks per 1000' at 7 Yrs
1	L-1	From	None	None	—	0	6½	11 5	9	13 0	11.8
	L-3	To	None	Contr	80'	12.5	6½	4.7	9	7 3	5.3
						+12 5		-6.8		-5 7	-6 6
2	L-3	From	None	Contr.	80'	12 5	6½	4 7	9	7 3	5 2
	L-3	To	None	Contr.	40'	25.0	6½	4.8	9	7 6	5.3
						+12 5		+0 1		+0 3	+0.1
3	L-2	From	Mesh	None	—	0	7	9.4	9	10.1	9.4
	L-6	To	Mesh	Contr.	80'	12 5	7	0.4	9	0.5	0.4
						+12 5		-9.0		-9 6	-9 0
4	L-6	From	Mesh	Contr.	80'	12 5	6½	0.4	9	0 5	0 4
	L-6	To	Mesh	Contr	40'	25.0	6½	0.6	9	0 6	0 6
						+12 5		+0 2		+0 1	+0 2
5	L-3	From	None	Contr.	40'	25.0	6½	4 8	8½	7 0	5 3
	L-4	To	None	Alt E-C	40'	25.0	6½	9.5	8½	12 8	10.4
						0		+4 7		+5.8	+5.1
6	L-6	From	Mesh	Contr.	40'	25 0	6½	0.6	8	0.6	0 6
	L-5	To	Mesh	Alt E-C	40'	25.0	6½	8.0	8	9.4	8.5
						0		+7.4		+8.8	+7 9
7	L-1	From	None	None	—	0	7	11.8	10	13 6	11 8
	L-2	To	Mesh	None	—	0	7	9.4	10	10.5	9.4
								-2.4		-3 1	-2.4
8	L-3	From	None	Contr.	80'	12 5	6½	4 7	9	7.3	5 2
	L-6	To	Mesh	Contr.	80'	12.5	6½	0.4	9	0.5	0.4
						0		-4 3		-6.8	-4 8
9	L-3	From	None	Contr.	40'	25 0	6½	4.8	9	7 6	5 3
	L-6	To	Mesh	Contr.	40'	25.0	6½	0.6	9	0.6	0 6
						0		-4 2		-7 0	-4 7
10	L-4	From	None	Alt E-C	40'	25.0	6	8.7	8	12 0	10.4
	L-5	To	Mesh	Alt E-C	40'	25.0	6	7.6	8	9 4	8.5
						0		-1 1		-2.6	-1.9
11	L-5	From	Mesh	Alt E-C	40'	25.0	5½	7.2	7	8.5	8 5
	L-5B	To	Mesh or Wat	Expans	40'	25.0	5½	11.1	7	12.2	12.2
						0		+3.9		+3.7	+3 7

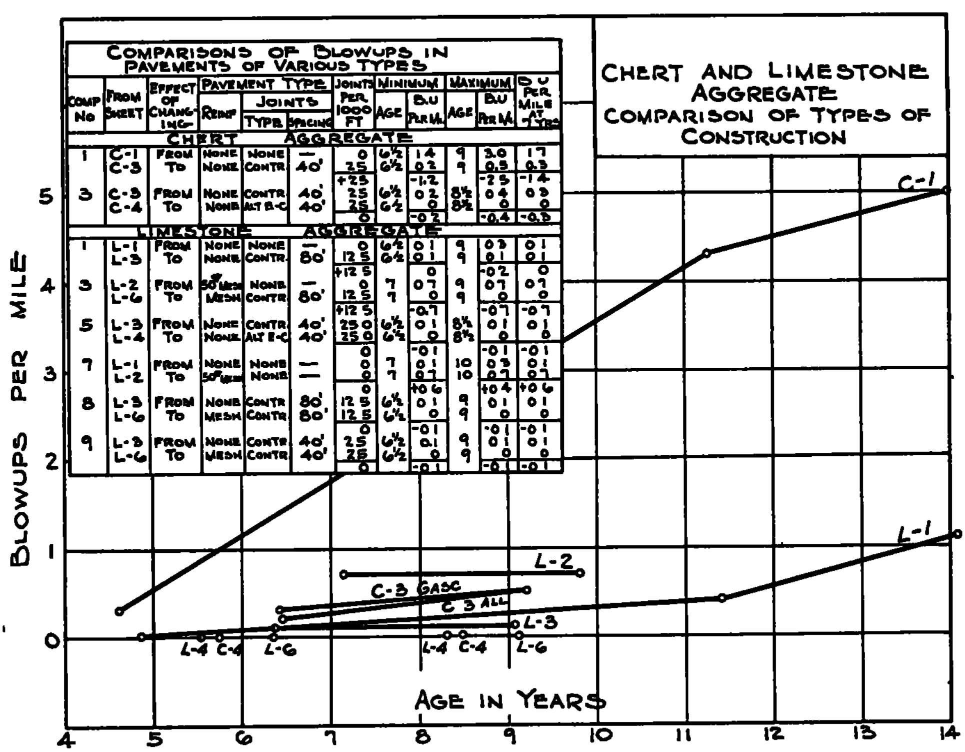
Figure 2



COMPARISONS OF CRACKING IN PAVEMENTS OF VARIOUS TYPES BUILT WITH CHERT FROM GASCONADE RIVER

Comp No	From Sheet	Effect of Changing	Pavement Type: Reinf	Joints: Type	Joints: Spacing	Joints per 1000 Ft: Contr	Joints per 1000 Ft: Exp	Minimum: Age	Minimum: CR/1000	Maximum: Age	Maximum: CR/1000	Cracks per 1000 at 8 Yrs
1	C-3	From	None	Contr	40'	25	0	6½	10 7	9	13 0	12 0
	C-3	To	None	Contr	20'	50	0	6½	4 0	9	5 7	5 0
						+25	0		-6 7		-7 3	-7 0
2	C 3	From	None	Contr	40'	25.0	0	6½	10 7	8½	12 5	12 0
	C-4	To	None	E C C C	40'	18 8	6 2	6½	15 2	8½	16 0	15 7
						-6 2	+6 2		+4 5		+3 5	+3 7
3	C-3	From	None	Contr	40'	25 0	0	6½	10 7	8½	12 5	12 0
	C-4	To	None	E-C C	40'	16 7	8 3	6½	16 8	8½	18.0	17 7
						-8 3	+8 3		+6 1		+5 5	+5.7
4	C-3	From	None	Contr	40'	25 0	0	6½	10.7	8½	12 5	12 0
	C-4	To	None	Alt E C	40'	12.5	12 5	6½	24 9	8½	25 4	25 2
						-12 5	+12 5		+14 2		+12 9	+13 2

Figure 3

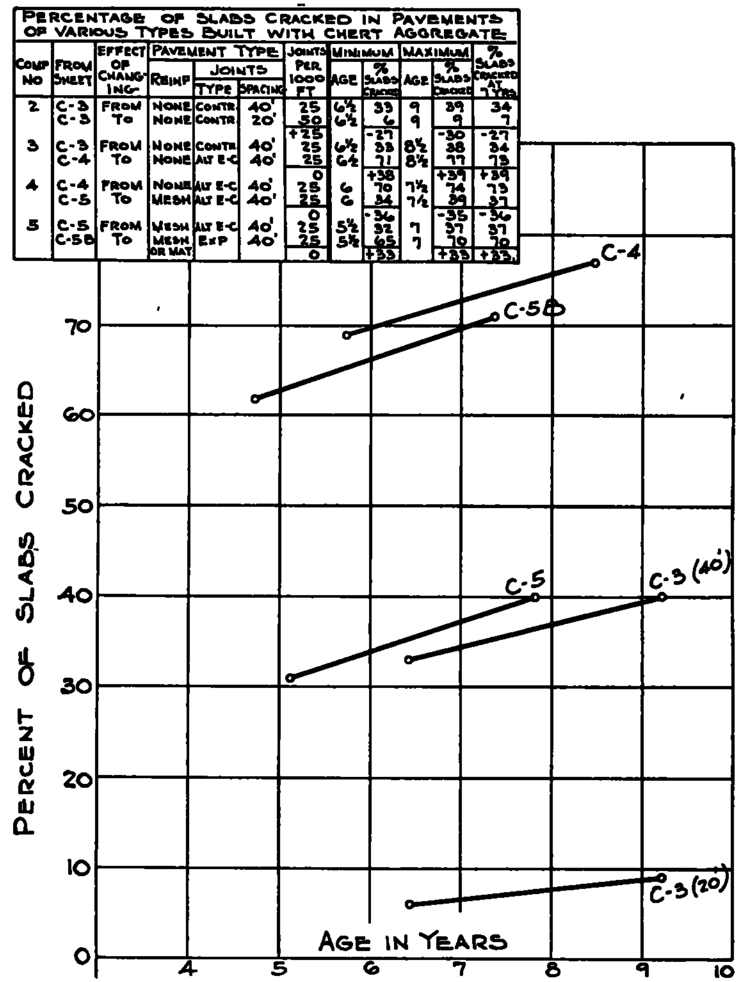


COMPARISONS OF BLOWUPS IN PAVEMENTS OF VARIOUS TYPES

Comp No	From Sheet	Effect of Changing	Pavement Type: Reinf	Joints: Type	Joints: Spacing	Joints per 1000 Ft	Minimum: Age	Minimum: B.U per M.	Maximum: Age	Maximum: B.U per M.	B U per Mile at 7 Yrs
CHERT AGGREGATE											
1	C-1	From	None	None	—	0	6½	1 4	9	3.0	1 7
	C-3	To	None	Contr	40'	25	6½	0 2	9	0.5	0.3
						+25		-1.2		-2 5	-1 4
3	C-3	From	None	Contr	40'	25	6½	0 2	8½	0 4	0 3
	C-4	To	None	Alt E-C	40'	25	6½	0	8½	0	0
						0		-0 2		-0.4	-0.3
LIMESTONE AGGREGATE											
1	L-1	From	None	None	—	0	6½	0 1	9	0 3	0 1
	L-3	To	None	Contr	80'	12 5	6½	0 1	9	0 1	0 1
						+12 5		0		-0 2	0
3	L-2	From	50# Mesh	None	—	0	7	0 7	9	0 7	0 7
	L-6	To	Mesh	Contr	80'	12 5	7	0	9	0	0
						+12 5		-0.7		-0 7	-0 7
5	L-3	From	None	Contr	40'	25 0	6½	0 1	8½	0 1	0 1
	L-4	To	None	Alt E-C	40'	25 0	6½	0	8½	0	0
						0		-0 1		-0 1	-0 1
7	L-1	From	None	None	—	0	7	0 1	10	0 3	0 1
	L-2	To	50# Mesh	None	—	0	7	0 7	10	0 7	0 7
						0		+0 6		+0 4	+0 6
8	L-3	From	None	Contr	80'	12 5	6½	0 1	9	0 1	0 1
	L-6	To	Mesh	Contr	80'	12 5	6½	0	9	0	0
						0		-0 1		-0 1	-0 1
9	L-3	From	None	Contr	40'	25	6½	0.1	9	0 1	0 1
	L-6	To	Mesh	Contr	40'	25	6½	0	9	0	0
						0		-0 1		-0 1	-0 1

Figure 4

figure, when contraction joints were spaced at 20-ft. intervals in unreinforced chert pavements, only about 9 per cent of the resulting 20-ft. slabs had cracked when the pavement was 9 years old. When a 40-ft. spacing was used approximately 39 per cent of the 40-ft. slabs cracked. A 40-ft. spacing in unreinforced limestone pavement prevented cracking in all but 29 per cent of the slabs at 9 years while 46 per cent of the 80-ft. slabs were cracked at the same age when the interval was doubled. In the reinforced limestone pavements very little cracking was found in either the 40- or 80-ft slabs. The mileage of reinforced pavement either without joints (Type L-2) or with contraction joints (Type L-6) is limited and consideration of the results shown by these types should be tempered by the fact that they do not include sufficient mileage to be conclusive.



PERCENTAGE OF SLABS CRACKED IN PAVEMENTS OF VARIOUS TYPES BUILT WITH CHERT AGGREGATE

Comp No	From Sheet	Effect of Changing	Pavement Type: Reinf	Joints: Type	Joints: Spacing	Joints per 1000 Ft	Minimum: Age	Minimum: % Slabs Cracked	Maximum: Age	Maximum: % Slabs Cracked	% Slabs Cracked at 7 Yrs
2	C-3	From	None	Contr.	40'	25	6½	33	9	39	34
	C-3	To	None	Contr.	20'	50	6½	6	9	9	7
						+25		-27		-30	-27
3	C-3	From	None	Contr.	40'	25	6½	33	8½	38	34
	C-4	To	None	Alt E-C	40'	25	6½	71	8½	77	73
						0		+38		+39	+39
4	C-4	From	None	Alt E-C	40'	25	6	70	7½	74	73
	C-5	To	Mesh	Alt E-C	40'	25	6	34	7½	39	37
						0		-36		-35	-36
5	C-5	From	Mesh	Alt E-C	40'	25	5½	32	7	37	37
	C-5B	To	Mesh or Mat	Exp	40'	25	5½	65	7	70	70
						0		+33		+33	+33

Figure 5

The use of contraction joints also reduced the number of blowups which would

normally occur in pavement without joints. This is shown in comparison 1 of Figure 4. The effect is much more noticeable in the chert aggregate pavements than in limestone pavements. At 7 yr. of age the use of contraction joints at 40 and a blowup every 4 miles (0 25 per mile) while the comparable pavement with joints had still only one every 10 miles

In the case of the chert aggregate pavements, the use of joints at 20 and 40-ft intervals in unreinforced pavements re-

PERCENTAGE OF SLABS CRACKED IN PAVEMENTS OF VARIOUS TYPES BUILT WITH CRUSHED LIMESTONE AGGR.

Comp No	From Sheet	Effect of Changing	Pavement Type: Reinf	Joints: Type	Joints: Spacing	Joints per 1000 Ft	Minimum: Age	Minimum: % Slabs Cracked	Maximum: Age	Maximum: % Slabs Cracked	% Slabs Cracked at 7 Yrs
2	L-3	From	None	Contr	80	12 5	6½	28	9	45	31
	L-3	To	None	Contr	40'	25 0	6½	16	9	29	18
						+12 5		-12		-16	-13
4	L-6	From	Mesh	Contr	80'	12 5	6½	3	9	4	3
	L-6	To	Mesh	Contr	40'	25 0	6½	2	9	3	2
						+12 5		-1		-1	-1
5	L-3	From	None	Contr	40'	25	6½	16	8½	29	18
	L-4	To	None	Alt E-C	40	25	6½	35	8½	47	37
						0		+19		+18	+19
6	L 6	From	Mesh	Contr.	40'	25	6½	2	8	3	2
	L-5	To	Mesh	Alt E-C	40'	25	6½	32	8	37	33
						0		+30		+34	+31
8	L-3	From	None	Contr	80'	12 5	6½	28	9	45	31
	L-6	To	Mesh	Contr	80'	12,5	6½	3	9	4	3
						0		-25		-41	-28
9	L-3	From	None	Contr.	40'	25	6½	16	9	29	18
	L-6	To	Mesh	Contr	40'	25	6½	2	9	3	2
						0		-14		-26	-16
10	L-4	From	None	Alt E C	40	25	6	31	8	44	37
	L-5	To	Mesh	Alt E C	40'	25	6	30	8	37	33
						0		-1		-7	-4
11	L-5	From	Mesh	Alt E C	40'	25	5½	28	7	33	33
	L-5B	To	Mesh or Mat	Exp	40'	25	5½	43	7	47	47
						0		+15		+14	+14

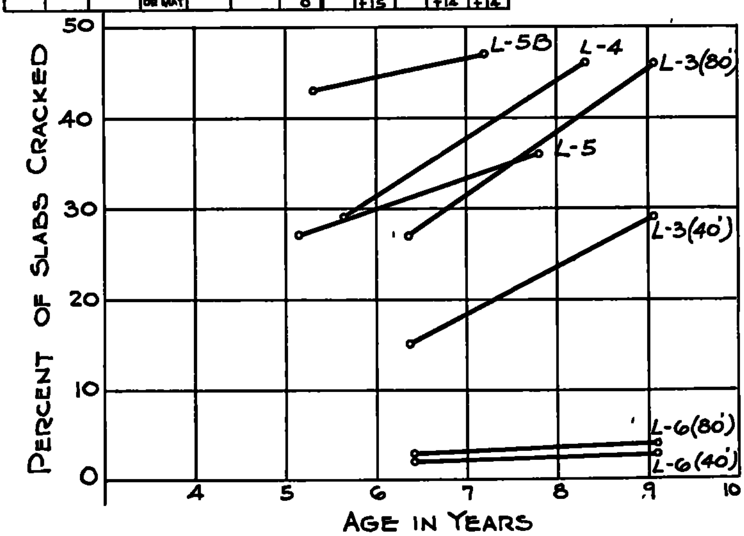
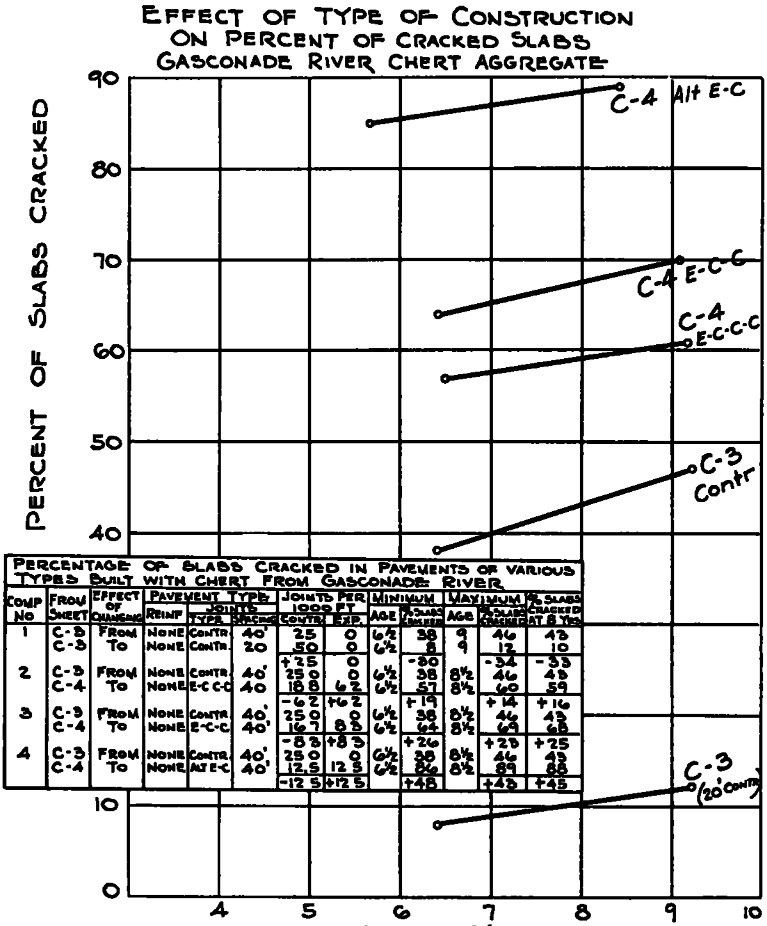


Figure 6

80-ft. intervals in unreinforced limestone pavements reduced the number of blowups from 0 15 per mile (one every 6.7 miles) to 0.10 per mile (one every 10 miles). This beneficial effect appears to be greater at later ages since at 9 yr. the pavements without joints had developed duced the number of blowups from 1.74 per mile (one every 3,040 ft.) to 0 27 per mile (one every 3 8 miles) at an age of 7 yr. At the age of 9 yr., the pavements without joints showed 2.95 blowups per mile (one every 1,800 ft.) while the comparable pavements with contraction joints

at 20 and 40 ft. had developed only 0.5 of a blowup per mile or one every 2 miles (10,560 ft.).

An accurate analysis of the value of contraction joints in controlling cracking would necessitate establishing some sort and data regarding intermediate spacings as well as longer intervals would be necessary to determine the optimum spacing at which the full benefit of contraction joints could be realized However, the data do indicate that the use of contraction joints



PERCENTAGE OF SLABS CRACKED IN PAVEMENTS OF VARIOUS TYPES BUILT WITH CHERT FROM GASCONADE RIVER

Comp No	From Sheet	Effect of Changing	Pavement Type: Reinf	Pavement Type: Joints Type	Pavement Type: Joints Spacing	Joints per 1000 ft: Contr.	Joints per 1000 ft: Exp.	Minimum: Age	Minimum: % Slabs Cracked	Maximum: Age	Maximum: % Slabs Cracked	% Slabs Cracked at 8 Yrs.
1	C-3	From	None	Contr.	40'	25	0	6½	38	9	46	43
	C-3	To	None	Contr.	20	50	0	6½	8	9	12	10
						+25	0		-30		-34	-33
2	C-3	From	None	Contr.	40'	25.0	0	6½	38	8½	46	43
	C-4	To	None	E-C C-C	40	18.8	6.2	6½	57	8½	60	59
						-6.2	+6.2		+19		+14	+16
3	C-3	From	None	Contr.	40'	25.0	0	6½	38	8½	46	43
	C-4	To	None	E-C-C	40'	16.7	8.3	6½	64	8½	69	68
						-8.3	+8.3		+26		+23	+25
4	C-3	From	None	Contr.	40'	25.0	0	6½	38	8½	46	43
	C-4	To	None	Alt E-C	40'	12.5	12.5	6½	86	8½	89	88
						-12.5	+12.5		+48		+43	+45

Figure 7

of ratio of the relative disadvantage of a crack as compared to a joint. Among the numerous factors that must be considered are cost data and maintenance records which are not available at this time to permit setting up such a relationship. The variation in contraction joint spacing with the two different kinds of aggregate is limited to two spacings only for each type is beneficial since they result in decreasing the blowups and have an appreciable effect in controlling cracking.

Effect of Substitution of Expansion Joints for Contraction Joints

When expansion joints were introduced, they were spaced at 80-ft. intervals and installed alternately with contraction

joints. Thus, in comparison with pavements containing contraction joints at a 40-ft. spacing, the net difference was the substitution of an expansion joint for each alternate contraction joint. The comparisons between Type 3 and Type 4 pavements show the effect of this change in design for unreinforced pavements. The comparison between Type L-5 and L-6 shows the effect of this change in reinforced limestone pavements. There were no reinforced chert pavements built with contraction joints so comparisons to show the effect of substituting expansion joints cannot be made for reinforced chert aggregate pavements.

As shown in Figure 1, comparison 3, the substitution of an expansion joint for alternate contraction joints in unreinforced chert aggregate pavements with contraction joints at 40 ft. resulted in an increase in transverse cracking of 11.6 cracks per 1,000 ft. at 7 yr. This difference in cracking is practically constant between the ages of about 6 to 9.

As shown in Figure 2, comparison 5, for limestone pavements without mesh having 40-ft. contraction joints, the substitution of an expansion joint for alternate contraction joints resulted in an increase of 5.1 cracks per 1,000 ft. at the age of 7 yr. This difference in cracking shows an increase between the ages of 6 and 9 and indicates the possibility that the additional cracking due to the expansion joints may be increasing with age. The effect of substituting expansion joints for contraction joints in limestone pavements with mesh is shown in comparison 6 of Figure 2. As before stated, the mileage of Type 6 pavements is limited and the data do not merit emphasis but since they show the same trend as is exhibited by other pavement types on which more extensive data are available, the comparison is pointed out.

As shown in the table on Figure 5, the substitution of an expansion joint for a contraction joint also reflects an increase in cracking when the pavements are compared on the basis of percentage of slabs that cracked. In comparison 3, it is seen that in unreinforced chert pavements only 34 per cent of the 40-ft. slabs were cracked when only contraction joints were used but when alternate expansion and contraction joints were used over twice as many (73 per cent) of the slabs cracked at the age of 7 yr. A study of the relative trends of the cracking of these two designs indicates that this differential may increase with age.

In the case of unreinforced limestone pavements the substitution of an expansion joint for a contraction joint also caused about twice as many slabs to crack. As shown in comparison 5 of Figure 6, only 18 per cent of the 40-ft. slabs bounded by contraction joints were cracked at 7 yr., while 38 per cent were cracked in comparable pavements wherein expansion joints were substituted. In this case, the increased cracking due to the expansion joints appears to be practically constant as the age of the pavements increases. In the reinforced limestone pavements, although the data may not be representative because of the limited mileage in Type 6, the effect of substituting expansion joints as shown in comparison 6 of Figure 6 is outstanding since only 2 per cent of the slabs in pavement having only contraction joints were cracked at 7 yr., while 33 per cent of the slabs in pavement with alternate expansion and contraction joints were cracked. In this case, likewise, the detrimental effect of the expansion joints shows a trend toward increasing with age.

The substitution of expansion joints for alternate contraction joints, which introduced 1 in. of expansion space every 80 ft., resulted in the elimination of all blowups. In other words, 1 in. of expansion space per 80 ft. was sufficient to eliminate blowups in both reinforced and unreinforced pavements built with either chert or limestone aggregate at least until

the age of about nine years The maximum benefit derived from expansion joints was realized in the unreinforced pavements in which they eliminated, on the average, one blowup every 2 miles where chert aggregate was used and one every 10 miles where limestone aggregate was used.

In a special group of projects, all built with chert from one source (Gasconade River) the effects accompanying the introduction of expansion joints in unreinforced pavement with 40-ft contraction joints is strikingly illustrated. A portion of these projects was constructed with contraction joints at 20 and 40-ft intervals; another portion with alternate expansion and contraction joints at 40-ft. intervals; another with an expansion joint followed by two contraction joints at 40-ft. intervals, and another portion was constructed with an expansion joint followed by three contraction joints at 40-ft. intervals. This construction made available information on the effect of substituting an expansion joint for alternate contraction joints; the effect of substituting an expansion joint for every third contraction joint and the effect of substituting an expansion joint for every fourth contraction joint.

Comparisons to bring out the effects of these variations on the transverse cracking are shown in tabulations on Figures 3 and 7. In both of these tables it can be seen that the cracking increased as the number of expansion joints increased. When one-fourth of the joints were expansion joints (as shown in comparison 2) there were 3.7 more cracks per 1,000 ft. and 16 per cent more of the slabs cracked at 8 yr. than when all the joints were contraction joints; when one-third of the joints were expansion joints (as shown in comparison 3) there were 5.7 more cracks per 1,000 ft. and 25 per cent more of the slabs cracked at 8 yr. than when all the joints were contraction joints; and when one-half of the joints were expansion joints (as shown in comparison 4) there were 13.2 more cracks per 1,000 ft. and 45 per cent more of the slabs were cracked at 8 yr. than when all joints were contraction joints.

On this particular group of projects, separate counts were made of the slabs, one end of which was adjacent to expansion joints, and those bounded at each end by contraction joints. Table 4 shows the cracks per 1,000 ft. and the percentage of slabs cracked when separated on this basis.

From this tabulation it can be seen that a larger percentage of the slabs adjacent to expansion joints were cracked and that these developed a greater number of

TABLE 4

	Slabs bounded by contraction joints				Slabs adjacent to the expansion joints				Project
	Cracks per 1000 ft		Slabs Cracked		Cracks per 1000 ft		Slabs cracked		
	1937	1939	1937	1939	1937	1939	1937	1939	
			%	%			%	%	
All contraction joints	10.9	13.7	40	51					239–B
1 expansion, 3 contraction joints	12.7	14.1	48	52	17.8	18.5	66	70	239–F
1 expansion, 2 contraction joints	14.5	16.1	56	61	17.7	19.5	68	75	239–E
1 expansion, 1 contraction joint					23.6	24.5	77	85	239–D

cracks per 1,000 ft. than the comparable slabs bounded by contraction joints. Furthermore, on the projects where a greater proportion of expansion joints were installed, the cracking in both the slabs bounded by expansion joints and in those adjacent to contraction joints was more severe than in comparable projects where a smaller proportion of expansion joints were used. Specifically, as observed in the 1939 survey, where no expansion joints were used, the slabs bounded by contraction joints had 13.7 cracks per 1,000 ft. and 51 per cent of them were cracked; on the portion where one-fourth of the joints were expansion joints, the slabs bounded by contraction joints had 14.1 cracks per 1,000 ft. and 52 per cent of them were cracked while the slabs adjacent to expansion joints had 18.5 cracks per 1,000 ft. and 70 per cent of them were cracked; on the portion where one-third of the joints were expansion joints the slabs bounded by contraction joints had 16.1 cracks per 1,000 ft. and 61 per cent were cracked while those adjacent to expansion joints had 19.5 cracks per 1,000 ft. and 75 per cent were cracked; and where half the joints were expansion joints the slabs bounded by expansion joints had 24.5 cracks per 1,000 ft. and 85 per cent of them were cracked. These figures show on this group of projects where the various pavements apparently should be directly comparable, that, without exception, the slabs adjacent to expansion joints developed more transverse cracks than the comparable slabs bounded by contraction joints and as the proportion of expansion joints was increased the cracking increased in both the slabs bounded by contraction joints and those adjacent to expansion joints.

Effect of Eliminating All Contraction Joints and Replacing Them With Expansion Joints

Of the designs discussed wherein expansion joints were substituted for contraction joints there were no pavements built with only expansion joints, since in all cases there were either one or more intermediate contraction joints between the expansion joints. In the Type 5-B pavements expansion joints were used to the exclusion of all contraction joints. Comparison of the cracking in pavements of Type 5-B having all expansion joints and Type 5 which has alternate expansion and contraction joints are shown in comparisons 5 of Figures 1 and 5 for reinforced chert pavements and comparisons 11 of Figures 2 and 6 for reinforced limestone pavements. No pavements were built with either aggregate which had expansion joints only and no reinforcement.

As shown in these comparisons, further substitution of expansion joints for contraction joints to the complete elimination of the latter also results in increased cracking in all cases. In the case of reinforced chert aggregate pavements at 7 yr. as shown in Figures 1 and 5, the increase was 8.5 cracks per 1,000 ft. and 33 per cent more of the slabs were cracked than in comparable pavements in which alternate joints were contraction joints. In reinforced limestone aggregate pavements at 7 yr., as shown in Figures 2 and 6, the increase was 3.7 cracks per 1,000 ft and 14 per cent more of the slabs were cracked than in comparable pavements having contraction joints spaced alternately with the expansion joints.

When the effect of substituting expansion joints for contraction joints at 40-ft spacing is summarized, the data indicate that the substitution of expansion joints has a beneficial effect in reducing the number of blowups but has a detrimental effect in causing increased cracking. Up to the age of about nine years no blowups were found in either reinforced or unreinforced pavements built with either of the aggregates when expansion joints were used, even when they were spaced at distances as great as 160 ft. in chert aggregate pavement. Since the chert aggregate

TABLE 5

CHERT AGGREGATE—COMPARISONS OF PAVEMENTS OF VARIOUS TYPES

Comparison No	Effect of change	Pavement type: Reinf	Pavement type: Joints: Type	Pavement type: Joints: Spacing	1937 survey: Age yr	1937 survey: Per 1000 ft: Joints	1937 survey: Per 1000 ft: Cracks	1937 survey: Slabs cracked	1937 survey: Per mile: Blow-ups No	1937 survey: Per mile: Crowft cracks No	1937 survey: Per mile: Corner breaks No	1937 survey: Per mile: Patches broken and/or depressed areas, sq ft	1939 survey: Age yr	1939 survey: Per 1000 ft: Joints	1939 survey: Per 1000 ft: Cracks	1939 survey: Slabs cracked	1939 survey: Per mile: Blow-ups No	1939 survey: Per mile: Crowft cracks No	1939 survey: Per mile: Corner breaks No	1939 survey: Per mile: Patches broken and/or depressed areas, sq ft
				ft				%								%				
1	From	None	None		4 62	0	26 1		0 3	1 0	15 4	38	9 21[a]	0	32 0[a]		3 1[a]	[b]	[b]	[b]
	To	None	Contr	40	6 44	25	9 0	33	0 2	3 4	1 4	29	9 21	25	10 9	40	0 5	7 6	5 1	196
						+25	−17 1		−0 1	+2 4	−14 0	− 9		+25	−21 1		−2 6			
2	From	None	Contr	40	6 44	25	9 0	33	0 2	3 4	1 4	29	9 21	25	10 9	40	0 5	7 6	5 1	196
	To	None	Contr	20		50	3 0	6						50	4 6	9				
						+25	−6 0	−27						+25	−6 3	−31				
3	From	None	Contr	40	6 44	25	9 0	33	0 2	3 4	1 4	29	9 21	25	10 9	40	0 5	7 6	5 1	196
	To	None	Alt E-C	40	5 73	25	20 2	69	0	0 3	1 7	21	8 47	25	21 9	77	0	1 0	5 2	150
						0	+11 2	+36	−0 2	−3 1	−0 3	−8		0	+11 0	+37	−0 5	−6 6	+0 1	−46
4	From	None	Alt E-C	40	5 73	25	20 2	69	0	0 3	1 7	21	8 47	25	21 9	77	0	1 0	5 2	150
	To	Mesh	Alt E-C	40	5 12	25	8 0	31	0	0	0 6	0	7 81	25	10 5	40	0	0	0 8	0
						0	−12 2	−38	0	−0 3	−1 1	−21		0	−11 4	−37	0	−1 0	−4 4	−150
5	From	Mesh	Alt E-C	40	5 12	25	8 0	31	0	0	0 6	0	7 81	25	10 5	40	0	0	0 8	0
	To	Mesh or mat	Expans	40	4 73	25	16 3	62	0	0	0 3	0	7 36	25	18 5	71	0	0 02	0 5	0
						0	+8 3	+31	0	0	−0 3	0		0	+8 0	+31	0	+0 02	−0 3	0

[a] Interpolated

[b] Not determined for this age

pavements naturally tended to develop more blowups when built without expansion joints than did the comparable limestone pavements, the beneficial effect of expansion joints was more noticeable in the former. In pavements built with both types of aggregates the introduction of expansion joints was accompanied by an increase in transverse cracking. The amount of cracking in pavements of all types was a minimum when all joints were contraction joints, the cracking increased with each increase in the proportion of expansion joints to contraction joints and the maximum amount of cracking was found when all of the joints were expansion joints. The magnitude of the increase in cracking was less for the pavements built with limestone aggregate than for those of the same design built with chert aggregate

From the foregoing data it appears that the expansion joints accomplished the purpose for which they were intended, i.e., the relief of high compression stresses that cause pavement blowups. Up to the age of 9 yr. 1-in expansion joints at 80-ft. intervals when used with alternate contraction joints have been effective in preventing blowups in both chert aggregate and limestone aggregate pavements. They prevented all blowups, even with chert aggregate and at intervals as great as 160 ft., when used with intermittent contraction joints at 40-ft. intervals However, this degree of success in eliminating blowups has been attained by sacrificing certain other desirable features

The data show definitely that the introduction of expansion joints is accompanied by a considerable increase in transverse cracking. This is universally recognized as being detrimental to concrete pavements since transverse cracks are in themselves structural failures and, in addition to being unsightly and difficult to maintain, are potential points for the inception of further deterioration such as raveling, spalling, corner breaking, crow-foot cracking and map cracking. Studies on numerous projects throughout the State have shown that a form of deterioration encountered in this area which results in map cracking is generally much worse in the pavement adjacent to expansion joints than in the pavement surrounding comparable, contiguous contraction joints or transverse cracks.

Pavements built with expansion joints cannot be constructed or maintained with as smooth a riding surface as those built without expansion joints. Consequently, rideability is sacrificed at the outset by introducing expansion joints. Furthermore, detailed investigations have shown that warping due to subgrade volume changes is invariably worse at expansion joints than at contraction joints or transverse cracks, and unless expensive sealed joints with adequate facilities for load transfer are used, rideability may be further impaired by the progression of warping.

In addition to these disadvantages the use of expansion joints introduces an economic problem. Expansion joints that provide satisfactory load transfer across the expansion space, a provision that is required to prevent load failures and warping, increase the cost of the pavement sometimes as much as 10 per cent. If all of these disadvantages resulting from the use of expansion joints are weighed against the sole advantage of eliminating blowups, the decision may be reached that in some cases expansion joints should be dispensed with entirely and in others that their spacing should be greatly increased or the free expansion space per joint be cut to a minimum.

Effect of Adding Mesh

Mesh reinforcement was used on several projects built with limestone and in others built with chert aggregate. These afford comparisons to bring out the effect of mesh in pavements of different design built with either aggregate.

TABLE 6

Limestone Aggregate—Comparisons of Pavements of Various Types

Comparison No	Effect of change	Pavement type: Reinf	Pavement type: Joints: Type	Pavement type: Joints: Spacing	1937 survey: Age yr	1937: Per 1000 ft: Joints	1937: Per 1000 ft: Cracks	1937: Slabs cracked	1937: Per mile: Blow-ups No	1937: Per mile: Crowft cracks No.	1937: Per mile: Corner breaks No	1937: Per mile: Patches broken and/or depressed areas, sq ft	1939 survey: Age yr	1939: Per 1000 ft: Joints	1939: Per 1000 ft: Cracks	1939: Slabs cracked	1939: Per mile: Blow-ups No	1939: Per mile: Crowft cracks No	1939: Per mile: Corner breaks No	1939: Per mile: Patches broken and/or depressed areas, sq ft
				ft				%								%				
1	From	None	None	80	4 86	0	10 5	27	0 01	0 3	2 4	0	9 07[a]	0	13 0[a]	46	0 3[a]	[c]	[c]	[c]
	To	None	Contr		6 37	12 5	4 6		0 1	0 5	1 0	130	9 07	12 5	7 4		0 1	2 3	5 6	269
						+12 5	−5 9		+ 09	+0 2	−1 4	+130		+12 5	−5 6		−0 2			
2	From	None	Contr	80	6 37	12 5	4 6	27	0 1	0 5	1 0	130	9 07	12 5	7 4	46	0 1	2 3	5 6	269
	To	None	Contr	40		25 0	4 6	15						25 0	7 7	29				
						+12 5	0	−12						+12 5	+0 3	−17				
3	From	Mesh	None	80	7 15	0	9 5	3	0 7[b]	0 4	2 6	174	9 81	0	10 4	4	0 7	0 6	6 8	862
	To	Mesh	Contr		6 42	12 5	0 4		0	0	0 4	0	9 11	12 5	0 5		0	0 4	0 5	0
						+12 5	−9 1		−0 7[b]	−0 4	−2 2	−174		+12 5	−9 9		−0 7	−0 2	−6 3	−862
4	From	Mesh	Contr	80	6 42	12 5	0 4	3	0	0	0 4	0	9 11	12 5	0 5	4	0	0 4	0 5	0
	To	Mesh	Contr	40		25 0	0 6	2						25 0	0 6	3				
						+12 5	+0 2	−1						+12 5	+0 1	−1				
5	From	None	Contr	40	6 37	25	4 6	15	0 1	0 5	1 0	130	9 07	25	7 7	29	0 1	2 3	5 6	269
	To	None	Alt E-C	40	5 64	25	8 1	29	0	0 07	0 5	2	8 30	25	12 5	46	0	0 14	1 2	6
						0	+3 5	+14	−0 1	−0 43	−0 5	−128		0	+4 8	+17	−0 1	−2 16	−4 4	−263
6	From	Mesh	Contr	40	6 42	25	0 6	2	0	0	0 4	0	9 11	25	0 6	3	0	0 4	0 5	0
	To	Mesh	Alt E-C	40	5 16	25	6 9	27	0	0	0 1	0	7 80	25	9 2	36	0	0 1	0 4	46
						0	+6 3	+25	0	0	−0 3	0		0	+8 6	+33	0	−0 3	−0 1	+46
7	From	None	None		4 86	0	10 5		0 01	0 3	2 4	0	9 81	0	13 5		0 3	[c]	[c]	[c]
	To	Mesh	None		7 15	0	9 5		0 70[b]	0 4	2 6	174	9 81	0	10 4		0 7	0 6	6 8	862
							−1 0		+0 69	+0 1	+0 2	+174			−3 1		+0 4			
8	From	None	Contr	80	6 37	12 5	4 6	27	0 1	0 5	1 0	130	9 07	12 5	7 4	46	0 1	2 3	5 6	269
	To	Mesh	Contr	80	6 42	12 5	0 4	3	0	0	0 4	0	9 11	12 5	0 5	4	0	0 4	0 5	0
						0	−4 2	−24	−0 1	−0 5	−0 6	−130		0	−6 9	−42	−0 1	−1 9	−5 1	−269
9	From	None	Contr	40	6 37	25	4 6	15	0 1	0 5	1 0	130	9 07	25	7 7	29	0 1	2 3	5 6	269
	To	Mesh	Contr	40	6 42	25	0 6	2	0	0	0 4	0	9 11	25	0 6	3	0	0 4	0 5	0
						0	−4 0	−13	−0 1	−0 5	−0 6	−130		0	−7 1	−26	−0 1	−1 9	−5 1	−269
10	From	None	Alt E-C	40	5 64	25	8 1	29	0	0 07	0 5	2	8 30	25	12 5	46	0	0 14	1 2	6
	To	Mesh	Alt E-C	40	5 16	25	6 9	27	0	0	0 1	0	7 80	25	9 2	36	0	0 1	0 4	46
						0	−1 2	−2	0	−0 07	−0 4	−2		0	−3 3	−10	0	−0 04	−0 8	+40
11	From	Mesh	Alt E-C	40	5 16	25	6 9	27	0	0	0 1	0	7 80	25	9 2	36	0	0 1	0 4	46
	To	Mesh or mat	Expans	40	5 31	25	11 0	43	0	0	0	0	7 20	25	12 3	47	0	0	0 16	0
						0	+4 1	+16	0	0	−0 1	0		0	+3 1	+11	0	−0 1	−0 24	−46

[a] Interpolated [b] Due to unusual method of laying mesh [c] Not determined for this age

In the case of the chert aggregate, wherever mesh was used, expansion joints were used also, so no data are available for reinforced chert pavements with only contraction joints. The comparisons between Types C-4 and C-5 show the effect of adding mesh reinforcement in chert aggregate pavements. Comparisons between Types L-1 and L-2, Types L-3 and L-6, and Types L-4 and L-5 show the effects of adding mesh reinforcement in pavements built with limestone aggregate. The mileage of Type L-2 pavements is limited and the use of continuous mesh is not only unusual but contrary to sound design, so the data referring to this type are not considered of much importance. Likewise since the mileage of Type L-6 pavements is too short to be representative and is confined to one locality, the data relative to this type should not be considered as typical. The comparisons involving these two types are shown since they are available but the comparisons between Types 4 and 5 are presented as indicative of the true relationship between the unreinforced and reinforced pavements.

Although the distributed reinforcement, as used, was not designed to prevent cracking but merely to hold tightly closed the cracks that might develop, the observations show that the mesh apparently did prevent some cracking. Practically all of the survey was conducted in cool weather when the cracks should have their maximum opening. In the entire mileage of mesh reinforced chert-aggregate pavement with joint intervals not exceeding 40 ft., and in the entire mileage of limestone aggregate pavement with joint intervals up to 80 ft., no crack was found which was open enough to indicate that the mesh has been broken or stressed beyond its elastic limit. On an experimental project (Route 50, Osage County) where joint spacings of 27, 40, 53, 66 and 80 ft. were used with chert aggregate, two cracks were found that were open enough to indicate that the mesh had been broken or its elastic limit exceeded. One of these was in an 80-ft. slab and the other in a 53-ft. slab. In general, however, it was strikingly evident that the cracks in reinforced pavements were more tightly closed that those in comparable unreinforced pavements and, furthermore, in every case, there were actually fewer cracks found in reinforced pavements than in the comparable unreinforced pavements.

As shown in comparison 4 of Figure 1, the introduction of mesh reinforcement into chert aggregate pavements with alternate expansion and contraction joints at 40-ft. intervals results in the elimination of 11.3 cracks per 1,000 ft. at 7 yr. Expressed in terms of the percentage of slabs cracked, as shown in comparison 4 of Figure 5, the introduction of mesh in this design resulted in a reduction in the percentage of slabs cracked from 73 per cent to 37 per cent. It is interesting to note in this particular case that the beneficial effect on cracking of the addition of mesh was quantitatively about the same as the detrimental effect of substituting expansion joints for alternate contraction joints. In other words, the addition of mesh in chert aggregate pavements had the effect at 7 yr. of practically counteracting the effect of introducing alternate expansion joints in pavements built with contraction joints at 40-ft. intervals.

The use of mesh appeared to be less effective in reducing cracking in limestone pavements than in chert aggregate pavements. As shown in comparisons 10 of Figures 2 and 6, the introduction of mesh in limestone pavements with alternate expansion and contraction joints was accompanied by the elimination of only 1.9 cracks per 1,000 ft. and a reduction in cracked slabs of from 37 per cent to 33 per cent at 7 yr. of age. In chert aggregate pavements, the introduction of mesh eliminated 11.3 cracks per 1,000 ft. and reduced the percentage of cracked slabs from 73 to 37. When the effect of adding

TABLE 7

Chert Aggregate From Gasconade River—Comparisons of Pavements of Various Types

Comparison No	Effect of change	Pavement type: Reinf	Pavement type: Joints: Type	Pavement type: Joints: Spacing	1937 survey: Age yr	1937 survey: Per 1000 ft: Joints	1937 survey: Per 1000 ft: Cracks	1937 survey: Slabs cracked	1937 survey: Per mile: Blow-ups No	1937 survey: Per mile: Crowft cracks No	1937 survey: Per mile: Corner breaks No	1937 survey: Patches broken and/or depressed areas, sq ft	1939 survey: Age yr	1939 survey: Per 1000 ft: Joints	1939 survey: Per 1000 ft: Cracks	1939 survey: Slabs cracked	1939 survey: Per mile: Blow-ups No	1939 survey: Per mile: Crowft cracks No	1939 survey: Per mile: Corner breaks No	1939 survey: Patches broken and/or depressed areas, sq. ft.
				ft				%								%				
1	From	None	Contr	40	6 42	25	10 6	38	0 3	5 9	1 8	53	9 22	25	13 1	47	0 5	10 2	6 3	175
	To	None	Contr	20		50	3 9	8						50	5 8	12				
						+25	−6 7	−30						+25	−7 3	−35				
2	From	None	Contr	40	6 42	25	10 6	38	0 3	5 9	1 8	53	9 22	25	13 1	47	0 5	10 2	6 3	175
	To	None	E-C-C-C	40	6 50	25	15 2	57	0	0	1 4	6	9 17	25	16 3	61	0	0	5 2	6
						0	+4 6	+19	−0 3	−5 9	−0 4	−47		0	+3 2	+14	−0 5	−10 2	−1 0	−169
3	From	None	Contr	40	6 42	25	10 6	38	0 3	5 9	1 8	53	9 22	25	13 1	47	0 5	10 2	6 3	175
	To	None	E-C-C	40	6 42	25	16 7	64	0	0	1 4	6	9 08	25	18 4	70	0	0	5 3	6
						0	+6 1	+26	−0 3	−5 9	−0 4	−47		+20	+5 3	+23	−0 5	−10 2	−1 0	−169
4	From	None	Contr	40	6 42	25	10 6	38	0 3	5 9	1 8	53	9 22	25	13 1	47	0 5	10 2	6 3	175
	To	None	Alt E-C	40	5 67	25	24 7	85	0	0	1 4	6	8 42	25	25 3	89	0	0	5 3	6
						0	+14 1	+47	−0 3	−5 9	−0 4	−47		0	+12 2	+42	−0 5	−10 2	−1 0	−169

TABLE 8

CHERT AGGREGATE — SUMMARY OF PAVEMENTS OF VARIOUS TYPES

Reinforcement	Joints		Miles surveyed	Age years	Slabs cracked	Per 1000 ft		Blowups per mile	No of projects with blowups	Crowfoot cracks per mile	Corner breaks per mile	Patches plus broken and/or depressed areas sq ft per mile
	Type	Spacing				Transverse						
						Joints	Cracks					
		ft			%							
None	None		50 04	4 62	.	0	26 1	0 3	7 of 14	1 0	15 4	38
			38 59	11 27	.	0	34 6	4 3	14 of 14	3 8	22 7	824
			38 16	14 00		0	38 1	5 0	14 of 14	8 4	38 9	1,439
None	Contraction	20	20 85	6 44	6	50 0	3 0	0 2	7 of 21	3 4	1 4	29
			20 29	9 21	9	50 0	4 6	0 5	13 of 21	7 6	5 1	196
None	Contraction	40	50 05	6 44	33	25 0	9 0	0 2	7 of 21	3 4	1 4	29
			46 29	9 21	40	25 0	10 9	0 5	13 of 21	7 6	5 1	196
None	Alternate E-C	40	39 01	5 73	69	25 0	20 2	0	0 of 12	0 03	1 7	21
			38 00	8 47	77	25 0	21 9	0	0 of 12	1 0	5 2	150
Mesh	Alternate E-C	40	20 90	5 12	31	25 0	8 0	0	0 of 9	0	0 6	0
			20 63	7 81	40	25 0	10 5	0	0 of 9	0	0 8	0 2
Mesh or mat	Expansion	40	37 12	4 73	62	25 0	16 3	0	0 of 16	0	0 3	0
			35 75	7 36	71	25 0	18 5	0	0 of 16	0 02	0 5	0

TABLE 9

LIMESTONE AGGREGATE — SUMMARY OF PAVEMENTS OF VARIOUS TYPES

Reinforcement	Joints: Type	Joints: Spacing	Miles surveyed	Age years	Slabs cracked	Per 1000 ft: Transverse Joints	Per 1000 ft: Transverse Cracks	Blowups per mile	No of projects with blowups	Crowfoot cracks per mile	Corner breaks per mile	Patches plus broken and depressed areas, sq ft per mile
		ft			%							
None	None		59 69	4 86		0	10 5	0 01	1 of 13	0 3	2 4	0
			53 58	11 41		0	14 5	0 4	9 of 13	2 0	5 4	139
			51 01	14 10		0	16 3	1 1	10 of 13	4 8	9 7	523
50-lb mesh	None		8 05	7 15		0	9 5	0 7	1 of 4	0 4	2 6	174
			7 98	9 81		0	10 4	0 7	1 of 4	0 6	6 8	862
None	Contraction	40	18 79	6 37	15	25 00	4 60	0 1	2 of 15			
			17 79	9 07	29	25 00	7 73	0 1	2 of 15	0 5	1 0	130
		80	24 04	6 37	27	12 50	4 60	0 1	2 of 15	2 3	5 6	269
			20 85	9 07	46	12 50	7 36	0 1	2 of 15			
36-lb. mesh	Contraction	40	3 07	6 42	2	25 00	0 56	0	0 of 3			
			3 04	9 11	3	25 00	0 60	0	0 of 3	0	0 4	0
		80	5 00	6 42	3	12 50	0 37	0	0 of 3	0 4	0 5	0
			4 39	9 11	4	12 50	0 48	0	0 of 3			
None	Alternate E–C	40	66 58	5 64	29	25 00	8 10	0	0 of 23	0 07	0 5	2
			64 50	8 30	46	25 00	12 52	0	0 of 23	0 14	1 2	6
Mesh	Alternate E–C	40	37 09	5 16	27	25 00	6 85	0	0 of 17	0	0 1	0
			35 94	7 80	36	25 00	9 20	0	0 of 17	0 1	0 4	46
Mesh or mat	Expansion	40	55 11	5 31	43	25 00	11 0	0	0 of 19	0	0	0
			53 48	7 20	47	25 00	12 3	0	0 of 19	0	0 16	0

mesh is compared to the effect of substituting expansion joints for alternate contraction joints in limestone aggregate pavements, it appears that, unlike chert aggregate pavements, the effect of expansion joints was greater than that of mesh. In other words, in limestone aggregate pavements the detrimental effect of expansion joints was not counteracted by the beneficial effect of the mesh to as great an extent as it was in chert aggregate pavements of the same design and age (7 yr.).

In the limestone aggregate pavements of other designs, although as previously stated the comparisons may have limited value, similar trends are shown and are presented to complete the evidence. As shown in comparisons 7, 8 and 9 of Figure 2, introduction of mesh into limestone aggregate pavements without joints, into those with contraction joints only at 80 ft., and into those with contraction joints only at 40 ft. caused a reduction of respectively 2.4, 4.8 and 4.7 cracks per 1,000 ft. at 7 yr. of age. As shown in comparisons 8 and 9 of Figure 6, the introduction of mesh in limestone aggregate pavements with contraction joints only at 80-ft. and 40-ft. intervals effected a reduction in slabs cracked of 28 and 16 per cent respectively at 7 yr.

To summarize the effect of adding mesh, the observations show that the mesh accomplished the desired purpose of holding cracks tightly closed. No crack was found open enough to indicate that the mesh had been stressed beyond its elastic limit in chert aggregate pavement with joint intervals as great as 40 ft. nor in limestone aggregate pavements with joint intervals as great as 80 ft. In addition, the mesh appeared to be effective in actually preventing some cracking. This effect was more noticeable in chert aggregate pavements where the mesh appeared to eliminate practically as many cracks as were caused by the substitution of expansion joints for alternate contraction joints. Although in limestone aggregate pavements, the beneficial effect of mesh was not as outstanding as in chert aggregate pavements, it did decrease the cracking some and in certain pavements practically eliminated it

SUMMARY

The following statements summarize the most important indications deduced from the comparisons cited

1. Pavements built with coarse aggregate produced from the chert deposits of Missouri naturally tend to develop more transverse cracks and blowups than comparable pavement built with crushed limestone aggregate, a fact which must be taken into consideration in any study of these defects. In unreinforced pavement without joints the difference may be as great as 22 cracks per 1,000 ft. and nearly four blowups per mile at 14 yr. of age. In pavements built with transverse joints, the difference in cracking varies from a minimum of 1.3 cracks per 1,000 ft. at 8 yr. to a minimum of 9.4 cracks per 1,000 ft at 8½ yr., or, expressed as a ratio, from 1.15 to 1.75 times as many cracks in the chert aggregate pavements as in comparable limestone pavements, depending upon the type and spacing of joints and whether or not the pavement was reinforced. In pavements built with contraction joints there are on the average five times as many blowups per mile at 9 yr. in those built with chert aggregate as in comparable pavements built with crushed limestone.

2. On the average and up to an age of 9 yr., the introduction of contraction joints at 40-ft intervals in unreinforced chert aggregate pavements is accompanied by a beneficial reduction in both transverse cracks and blowups. Expressed quantitatively, this introduction of 25 joints per 1,000 ft. effects on the average a reduction of 19.3 cracks per 1,000 ft. and 1.4 blowups per mile at the age of 7 yr. The introduction of an additional

TABLE 10

CHERT AGGREGATE FROM GASCONADE RIVER — SUMMARY OF PAVEMENTS OF VARIOUS TYPES

Reinforcement	Joints		Miles surveyed	Age years	Slabs cracked	Per 1000 ft		Blowups per mile	No of projects with blowups	Crowfoot cracks per mile	Corner breaks per mile	Patches plus broken and depressed areas, sq ft per mile
	Type	Spacing				Transverse						
						Joints	Cracks					
		ft			%							
None	Contraction	20	9 12	6 42	7 6	50	3 9	0 3	4 of 9	5 9	1 8	49
			8 74	9 22	11 7	50	5 8	0 5	7 of 9	10 2	6 3	178
None	Contraction	40	19 51	6 42	37 8	25	10 6					.
			17 70	9 22	47 4	25	13 1					
None	Alternate E-C	40	10 52	5 67	84 7	25	24 8	0	0 of 3	0	1 4	6
			10 36	8 42	89 3	25	25 3	0	0 of 3	0	5 3	6
None	E–C–C	40	4 34	6 42	64 0	25	16 7	0	0 of 1	0 2	0 9	0
			4 26	9 08	70 0	25	18 4	0	0 of 1	2 1	1 4	1
None	E–C–C–C	40	4 03	6 50	57 3	25	15 2	0	0 of 1	0	0 5	0
			3 92	9 17	61 4	25	16 3	0	0 of 1	1 8	2 0	1

25 joints per 1,000 ft. (a 20-ft. interval) results in a further reduction of 6.1 cracks per 1,000 ft. at 7 yr.

3. On the average and up to an age of 9 yr., the introduction of contraction joints at 80-ft. intervals in either reinforced or unreinforced limestone aggregate pavements is accompanied by beneficial reductions in both cracking and blowups. In the unreinforced pavements these 12.5 joints per 1,000 ft. eliminate on the average 6.6 cracks per 1,000 ft. and reduce the blowups from 0.15 to 0.10 per mile. In the reinforced pavements the 12.5 joints result on the average in a reduction of 9.0 cracks per 1,000 ft. at 7 yr. The introduction of an additional 12 5 joints per 1,000 ft. (a 40-ft. joint spacing) causes practically no change in either the amount of cracking or the number of blowups.

4. Up to the age of 9 yr., the substitution of expansion joints for contraction joints in unreinforced chert aggregate pavement with 40-ft. joint spacing is invariably accompanied by an increase in the transverse cracking and apparently benefits the pavement only to the extent of eliminating on the average one blowup every 2 miles. The increase in cracking due to the introduction of expansion joints is appreciable even when only one-fourth of the joints are expansion joints and, as the proportion of expansion joints is increased, the amount of cracking also increases. Quantitatively this effect at the age of 8 yr. can be expressed as follows: An increase of about four cracks per 1,000 ft. accompanies the substitution of expansion joints at the rate of 6.2 per 1,000 ft., an increase of about six cracks per 1,000 ft. with the substitution of 8.3 joints per 1,000 ft., and an increase of about 13 cracks per 1,000 ft. when 12.5 expansion joints per 1,000 ft. are substituted for the same number of contraction joints.

5. On the average and up to the age of 7 yr. in reinforced chert aggregate pavement with 40-ft. joint spacing, increasing the number of expansion joints to 100 per cent (an increase of 12.5 expansion joints per 1,000 ft.) is accompanied by a further increase of 8.5 cracks per 1,000 ft. more than develop in pavement with alternate expansion and contraction joints. Increasing the number of expansion joints does not reflect any benefit in reducing blowups since all blowups were eliminated in chert aggregate pavements by expansion joints at 80-ft. intervals.

6. On the average and up to the age of 7 yr. in either unreinforced or reinforced limestone pavement with 40-ft. joint intervals the substitution of an expansion joint for alternate contraction joints was accompanied by an increase in the amount of cracking, and, of course, no decrease in the number of blowups since these were reduced to zero by the use of contraction joints alone. The substitution of 12 5 expansion joints per 1,000 ft. for contraction joints was accompanied by an increase of 5.1 cracks per 1,000 ft. in unreinforced limestone pavement and by an increase of 7.9 cracks per 1,000 ft. in reinforced limestone pavements.

7. On the average and up to the age of 7 yr. in reinforced limestone aggregate pavement with 40-ft. joint spacing, increasing the number of expansion joints to 100 per cent (an increase of 12 5 expansion joints per 1,000 ft.) is accompanied by a further increase of 3.7 cracks per 1,000 ft. more than develop in pavement with alternate expansion and contraction joints and by no decrease in the number of blowups, since these were reduced to zero by the use of contraction joints alone

8. On the average and up to the age of 7 yr., the introduction of mesh in pavements built with either chert or limestone aggregate is accompanied by a substantial decrease in cracking. In chert gravel pavement with alternate expansion and contraction joints at 40-ft. spacing, 11.3 cracks per 1,000 ft. are eliminated by the introduction of mesh. In limestone aggre-

gate pavements of the same type, the introduction of mesh eliminates 1 9 cracks per 1,000 ft The use of 44-lb mesh has prevented open cracks in slab lengths up to 40 ft with chert aggregate and 80 ft with limestone aggregate

CONCLUSION

The summary indicates the tendencies of pavements in Missouri to develop cracks and blowups Based upon these observed tendencies and tempered by the authors' judgment and experience as to the relative disadvantages of cracks and blowups as compared to joints, the following conclusions have been drawn from the data collected as being applicable for use in an economical design practice under the conditions existing in this State

1 For standard concrete pavements built with either of the two principal types of aggregates commonly used in Missouri and under the average conditions prevailing in this State, the use of contraction joints is highly beneficial Spacings as great as 70 ft in reinforced limestone aggregate pavement and 40 ft in reinforced chert aggregate pavement will effect a material reduction in blowups and should control cracking within economically practical limits

2 Under average conditions in Missouri expansion joints are not necessary but, in fact, are detrimental in pavement built with the commonly used crushed limestone aggregate, providing contraction joints are installed at suitable intervals to provide efficient crack control

3 Under average conditions the use of expansion joints causes increased transverse cracking in pavements built with either chert aggregate or crushed limestone However, in pavement built with chert aggregate some provision for expansion is probably necessary to provide the degree of control of blowups generally considered desirable

4 Under average conditions in this state, the use of mesh tends to decrease transverse cracking and to prevent the opening of cracks when formed

DISCUSSION ON JOINTS IN CONCRETE PAVEMENT

MR R C YEOMAN In counting the transverse cracks do you discriminate against those cracks caused by settlement under culverts or the like, which could in no way be attributed to the number of joints, lack of joints or too many joints?

MR REAGEL I am sorry that in trying to condense I have eliminated some information of this type We took care of the number and size of depressed areas, settlement cracks, and particularly mud jacked areas by making exceptions of them They are not included in the tabulations