ditions under which gravel occurs. It is believed that surveying via the media of airphotos will make it possible to locate granular deposits more accurately, more efficiently, more rapidly and at a greater saving in cost than by land surveying.

CONDITION OF CONCRETE PAVEMENTS IN KANSAS AS AFFECTED BY COARSE AGGREGATE

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SYNOPSIS

In a survey made under the direction of Kansas State College Engineering Experiment Station and the Materials Department of the Kansas Highway Commission, 330 highway projects were examined comprising 1170 miles of concrete pavement

The purpose of survey was to investigate the relationship between certain classes of failure (mainly D-lines) and the materials incorporated into the concrete, (principally the coarse aggregate).

The coarse aggregate consisted of five general types, crushed limestone including one crushed sandstone, chert gravels, crushed flint, flint chats, sand gravel (mixed aggregate) Sand came from two general sources—Kaw river valley and Arkansas river valley Frequency of D-lines occurrence is 38 per cent for each sand, which was considered to be a uniform material in this study

Cement was from 12 or more sources Many old records do not give brand used; some projects have used several brands Although the influence of the composition of various types of cement is known to be of importance in the service life of a pavement it is considered here as uniform throughout the pavements examined

Coarse aggregate came from 60 different sources Some appear only once or twice In order to consolidate into groups for comparative service records the coarse aggregates were gathered into 13 commercial sources and 9 vicinity sources.

Each pavement was rated Good, Fair or Poor depending on the frequency and extent of failures counted per mile in D-line disintegration (material failure)

Lincoln Sandstone, Garnett limestone, Douglas gravel, Holiday gravel, Ottawa limestone, Johnson-Miami Counties limestone, Dickinson County limestone and flint chat show very good records over life periods of 10 to 25 years

Moline limestone, Bazaar gravel, Joplin flint and Kansas City limestone show predominantly poor records

The examination was based upon the condition of the concrete as a material rather than the condition of the slab The survey points out the relationship between one set of conditions (the CA component) and is limited to one type of failure (disintegration as a material)

It is not intended to imply that the cause and effect of such failures are limited to the relationships between the coarse aggregate and D-crack failures It is intended to convey the thought that this particular relationship is highly significant and should contribute to the selection of better coarse aggregates for Kansas concrete highways of the future.

Serious deterioration and severe damage has occurred in many concrete pavements in Kansas. These conditions have been aggravated in the past few years by increased heavy traffic and curtailed maintenance programs, both brought about by the war. The causes of such damage and deterioration are known to be numerous, and complete evaluation of them would require an investigation of great magnitude It is the purpose of this survey to investigate one phase of the problem, namely the influence of the component materials upon the service lives of the pavements involved. The effect of the coarse aggregate used in each pavement is the principal consideration.

This survey was instituted by the Engineering Experiment Station of Kansas State College, in cooperation with the Materials Department of the Kansas Highway Commission. C. H. Scholer, Professor of Applied Mechanics and Director of the Kansas Road Materials Laboratory, and R. D. Finney, Engineer of Materials, directed the work of the two agencies respectively. Professor L. V. White of the Civil Engineering Department, Kansas State College actively conducted the survey, assisted by several members of the staff of the two agencies.

SCOPE OF SURVEY

The survey was started late in the fall of 1944 and completed in the late summer of 1945. Three hundred thirty projects, comprising some 1170 miles of concrete pavement were examined. This mileage is about 85 per cent of the total mileage of concrete pavements in the state. The unsurveyed sections were isolated short stretches not included on through routes and some very old sections The pavements included in the survey are considered representative of the omitted sections. Table 1 showing the distribution of the pavement projects according to date of construction indicates that a well balanced condition exists over the total time period included in the survey About 25 per cent of the mileage surveyed was constructed in each of four 5-yr. periods into which the total time covered was divided. The fourth period (1935–1945) may be considered as a 5-yr. construction period, for only eight projects of a total of 101 were constructed after 1940

TABLE 1

Period Number	Date of Period Present Age	Number of Projects	Per cent of Total Projects	Number of Survey Miles	Per cent of Total Survey Miles
1	1919–1924 over 20 yrs	71	21	316	27
2	1925–1929 16–20 yrs	66	20	247	21
3	1930–1934 11–15 yrs	92	28	326	28
4	1935–1945 0–10 yrs	101	31	282	24
Totals	1919–1945 0–26 yrs.	330	100	1,171	100

The average length of each project surveyed is about 3 5 miles

CHARACTER OF DATA

The data were secured in the field and from the construction records of each project examined. The field data consist of a crack or failure count of six specified types of failures, a small chip sample from each pavement, and photographs of representative and unique conditions found during the course of the field examinations. The data from the construction records include the project number, length in miles, location by county, yield cement factor, plan cross-section, joint layout, joint type, aggregate types and sources, brand of cement used, specifications, and any other information pertinent to the objectives of this survey, for each project included in the survey. All of this information is not shown in the tabulations of data included in this report. For brevity, only data bearing on the subjects discussed are included.

For the purposes of this survey, six types of cracking or failures in concrete pavements were defined and a count of the number of each type present in each pavement project examined, was made Pavement failure types were divided into two general groups:

(1) Three degrees of cracking due to overtressing the slab without reference to the cause of overstressing, called "load failures" or "structural failures"

(2) Three degrees of cracking or failures due to the disintegration of the concrete, either accompanied by a failure of the first group type or by disintegration alone

The second type of crack is referred to as "disintegration" or "D-cracks." For convenience in making the crack count in the field the six degrees of cracking in the two groups were numbered and defined as shown in Table 2.

The "structural" or "load" failures counted in this survey were of the interior and exterior edge and corner type as defined in Table 2.

Uniform transverse cracking, serpentining longitudinal cracking, and cracking over and adjacent to rigid structures were not counted. The disintegration failures counted in this survey are of the type characterized by many fine parallel lines closely spaced and filled to extrusion with a black gel. The terms "D-lines" or "D-cracks," are used in reference to this failure type

"Map-cracking" found in mixed aggregate pavements is typified by many fine interconnecting cracks in the pavement, outlining small areas of from four to eight inches

TABLE 2
EXPLANATION OF FAILURES

Group I Load Failures Only	Group II Load Failures and Material Deterioration
No 1 Corner breaks with no evidence of progressive breaking or displacement No evidence of D-cracks or scaling.	No 4 D-cracks at corners and joints Little evidence of structural failure or if present, similar to No. 1
No 2 Corner breaks extending and joining Definite evidence of progressive breaks in direction of traffic movement No sign of D-cracks or scaling	No 5 Progressive breaking up in narrow strips, not typical corner breaks Breaking occurring in the direction against traffic, as well as with traffic D-cracks occurring under light traffic D-cracks may be serious without breaking up of pavement
No 3 General breaking down of pavement into irregular blocks, accompanied by displacement and faulting No evidence of D-cracks or scaling.	No 6 Marked evidence of D-cracks over much of pavement, together with progressive load failures (both with and against traffic), at joints

in their greatest dimension The general appearance of concrete fractured in this manner is not unlike the appearance of a heavily lined map Such failures are often of considerable area, extending the full width of the slab and longitudinally, in some sections, the full length of a project

"Map-cracking" and "D-lines" are two distinctly different failure types Map-cracking is defined here in order to avert confusion of the two types in the following discussions.

The terms used herein are definitive for this survey and do not necessarily encompass all types of concrete failures commonly referred to by the same or similar designations

Small samples of concrete were secured from each project in the course of the survey. These samples were used to verify the aggregate types involved, if possible, then identified and taken to the laboratory for future investigation by geologists and petrographers

Photographic evidence of the various types of cracking was secured. The figures accompanying this report are representative of the photographs taken during the field work

Notes concerning the general condition of each pavement were made and any unusual features observed were recorded.

PROCEDURE

The field work was accomplished by either walking or driving over the full length of each pavement surveyed. Only a few projects were examined by walking over them Most of the work was done by driving at speeds of from five to seven miles per hour over the project with one or two observers mounted on the front fenders of the car to make the crack count and record the data and observations. Samples were secured from the edge of the slab with a stone hammer. The locations from which the samples were taken were recorded and the aggregates identified and checked in the field with the construction records. Additional samples were secured if the construction records indicated several types in one project, or if the samples failed to check with the records Identification of the aggregate source was of primary importance and every effort was made to secure correct data in this respect.

The crack count was recorded by tallying the count in the six categories as observed in the field. This count was later transferred to a permanent card record and the count per mile for each type was then calculated The card record also contains the sample locations, pavement layout and all the data secured from the construction records.

AGGREGATES

Aggregates available for the production of portland cement concrete in Kansas at this time may be divided into five general types: (1) crushed stone, (2) chert gravels, sometimes crushed, (3) crushed flint, (4) flint chat, and (5) sand-gravel (mixed aggregate).

Crushed stone is the most widely used of the coarse aggregates All the crushed stones mentioned in this report are limestones with the exception of the sandstone from

Lincoln, Kansas. Limestone is secured from numerous quarries in Eastern Kansas and from the vicinity of Kansas City, Missouri. The physical properties of the various limestones are similar. They range in color from dark brown through gray to white. Some are quite soft while others are of medium hardness. Hard limestones are a rarity. Typical values of Los Angeles wear tests on limestones range from about 25 to 40 per cent loss. Present specifications limit the loss in this test to 50 per cent for concrete pavements. Absorptive qualities of the acceptable limestones range from 0 3 per cent up to about 4.0 per cent. Durability as determined by the loss ratio method of freezing and thawing is about equal in most of the acceptable limestones. Present specifications limit the loss ratio to a minimum of 0 9 Various specifications for gradation have been used in the past. The maximum size of 2 inches is the largest used, 1½ inches is quite common, grading downward to the No. 4 size.

The Lincoln sandstone is called "quartzite" but its cementing material is calcareous rather than siliceous, so it is not a true quartzite It is a hard stone ranging in color from dark brown to light, almost white, sand color. It sustains rather high losses in the Los Angeles wear tests, 40 to 50 per cent and has a low absorptive value. Its durability is high as measured by the freezing and thawing test.

The chert gravels available for concrete come principally from two sources. Bazaar gravel is a residual chert gravel found in the flint hills of Chase county. It is multicolored ranging from dark brown to white. Most of it is hard and flinty but some is partially decomposed and laminated, with the appearance of shale.

Holliday gravel is produced in Johnson county near the Kaw River at Holliday. It is of glacial origin and carries a wide variety of mineral constituents with chert and limestone predominating It is of more uniform color than the Bazaar, usually a dark reddish brown. Both of these materials are harder than the limestones They sustain low losses in wear tests, have high durability coefficients by freezing and thawing, and relatively low absorptive characteristics.

Arkansas City gravel and Neosho River gravel are washed materials obtained from the Walnut and Neosho rivers respectively. The supply from these two sources is limited and they have not been extensively used in pavement construction. Their properties are similar to those of the Bazaar and Holliday gravels. Due to their origin their particle shape is rounded and smooth textured.

Silverdale-Douglas gravel is a residual chert material, the source of which is now nearly exhausted. It is a dark reddish brown material with properties similar to those of the other cherts.

Crushed flint and flint chat are from the same general source, the lead and zinc mining district in southeast Kansas. Crushed flint is a coarse aggregate made by crushing flint boulders. It has been extensively used in the past. Flint chat is produced in the process of milling lead and zinc ores It is a small sized material, ½ inch maximum size, grading down to the No. 200 mesh size. Both flint aggregates have low losses in wear tests, 20 to 30 per cent, low absorptive values, high durability in freezing and thawing, and are very hard. The particles are sharp edged, splintery, and difficult to use from a workability standpoint. They range in color from black to white, with blue and gray predominating.

Sand-gravel mixed aggregate is secured from two general sources in this State, the Arkansas River and its tributaries and the Kansas River with its tributaries. Sand-gravel is a material familiar to many. It is of small maximum size, usually about ¼ inch, grading down to the No. 100 mesh size. It is pumped from river and stream beds, washed and graded. Its physical properties are similar in all localities Sand-gravel is characterized by its low absorptive value, high resistance to wear and high durability in freezing and thawing It is formed by the natural weathering and disintegration of the parent rocks in which the streams rise

Fine aggregates or sands used in the pavements examined in this survey also come from the two general sources of sand-gravel mentioned above In addition a few pavements were constructed using flint sand from the lead and zinc mines of southeast Kansas. The properties of the two natural sands are similar to those stated above for the sand-gravel mixed aggregates except for variations in sizing Flint sand is similar in character to the fine chat. A study of the data with regard to fine aggregates indicates that they have a relatively small influence with respect to the formation of the type of failures herein reported. Of the projects examined 65 per cent contained Kaw River sand, 30 per cent contained Arkansas River sand, 2 per cent contained both sands, 1 per cent contained flint sand and 2 per cent were unidentified With reference to the Group II failure type, or D-lines, the frequency of occurrence was found to be about equal in pavements containing the two natural sands. Of each group of projects containing these two aggregates 38 per cent were found to suffer from this type of damage It can therefore be concluded that the influence of the fine aggregates, with respect to this type of deterioration may be considered uniform throughout the pavements studied in this survey

CEMENT

Portland cement from about twelve different sources in Kansas, Oklahoma, and Nebraska were used In many projects several brands were used, the distribution of which is not ascertainable from the records. An attempt to correlate the defined failure types with a given cement is too complex a problem to include here Although the influence of the composition of the various types of cement is known to be of importance in the service life of a pavement, it is considered here as uniform throughout the pavements examined in this survey.

AGGREGATE SOURCES

Aggregates from some 60 locations were tabulated by name, in the data secured from the construction records. Some sources furnished aggregates for numerous pavement projects while others appear only in one or two projects. In order to consolidate these sources into groups for the purpose of comparing their service records they were divided into three divisions, (1) commercial sources, (2) vicinity sources, and (3) mixed-aggregate sources Under these headings 25 sub-groups were formed comprising aggregates of similar characteristics Commercial sources are those which have large capacity and have been distributed over relatively large areas of the state. Also included in this group are sources which have supplied aggregates for several pavement projects. Vicinity sources are those which have supplied aggregates to only a few projects but by their proximity to other sources, are considered to be of sufficient similarity to be classed as one source. These groups are shown in tabular form in Table 3.

TABLE 3

Coarse Aggregates			
	Commercial Sources		Vicinity Sources
1.	Lincoln Sandstone	1	Kansas City Limestone
2	Bazaar Gravel	2	Topeka Limestone
3	Garnett Limestone	3	Ottawa Limestone
4	Joplin Flint	4	Johnson-Miami Co Limestone
5	Moline Limestone	5	Chanute Limestone
6	Douglas-Silverdale Gravel	6	Ft Scott Limestone
7	Atchinson Limestone	7	Montgomery Co Limestone
8	Arkansas City Gravel	8	Lawrence Limestone
9	Holliday Gravel	9	Dickinson County Limestone
10	American Rock Crusher Limestone		
11	Neosho River Gravel		
12	Chat		
13	Cement City		

Mixed Aggregates	
1	Arkansas River Valley
2	Kaw River Valley
3	Blue River Valley

PAVEMENT CONDITION

The influence of the coarse aggregate in a given pavement was studied by rating each pavement as to its condition with respect to the frequency of occurrence and severity of the failures in group II (see Table 2). The data tabulated in group I, load failures, may be used as a guide in planning resurfacing projects, patching projects, and for other purposes Further discussion of these data will be omitted here in order to present a more complete discussion of the disintegration type of failure and its relationship to the component materials in the pavement.

Each pavement project was rated as good, fair, or poor, depending on the frequency and extent of the failures counted in categories 4, 5, and 6. A pavement was considered to be in good condition if it contained no more than six No 4 failures with no No 5 or No. 6 failures Fair condition included pavements with more than 6 and less than 26 No 4 failures, with no No 5 or No. 6 failures. Pavements containing more than 25 No 4 failures, or any No. 5 or No. 6 failures were rated as poor These ratings were determined by detailed study of the data In as much as this type of failure almost invariably starts at a joint in the pavement, or at a transverse crack, and the joint spacing is roughly 50 to the mile in all pavements, it may be seen that a pavement rated good, suffers from this

TABLE 4
SOURCE DISTRIBUTION OF CONCRETE PAVEMENT AGGREGATE—PERCENTAGE OF SURVEY MILES

Period No	I	II	III	IV	Total
Period / Source	1919 thru 1924 (over 20 yr)	1925 thru 1929 (16–20 yr)	1930 thru 1934 (11–15 yr)	1935 thru 1945 (0–10 yr)	1919 thru 1945 (0–26 yr)
Commercial Sources	42 4	34 0	55 9	45 7	45 2
Vicinity Sources	46 6	42 4	20 7	29 5	34 5
Mixed Agg Sources	11 0	23 6	23 4	24 8	20 3

arbitrary and it is realized that some border line cases may be unjustly rated. No doubt differences of opinion as to these ratings may arise. However it is considered impractical to divide the data into more than three classes and these three as defined are conservative. The complete data are not included here because of the great volume, but an appendix has been prepared containing all the recorded data secured in this survey and is available for inspection at the Kansas Highway Department offices in Topeka

Table 4 shows the distribution of aggregates, by sources, in the pavements surveyed. The gradual change from vicinity sources to commercial sources is indicated In the first

TABLE 5
DISTRIBUTION OF COARSE AGGREGATES BY SOURCE, CONDITION, AND TIME PERIOD—PERCENTAGE OF SURVEY MILES

Period Number	I			II			III			IV			Total Time		
Period	1919 thru 1924 (over 20 yr)			1925 thru 1929 (16-20 yr)			1930 thru 1934 (11–15 yr)			1935 thru 1945 (0–10 yr)			1919 thru 1945 (0–26)		
Source / Condition	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Commercial Sources															
Lincoln Sandstone			3 1*	2 9			14 3			8 9			5 9		0 9
Bazaar Gravel												13 8			3 1
Garnett Limestone	0 7	1 0								4 4		0 1	1 2	0 3	0 1
Joplin Flint	6 7	1 8	19 8			8 7							2 0	0 5	7 8
Moline Limestone	0 2			0 2			6 7	3 0	22 6	11 2	2 1	8 2	4 5	1 3	7 8
Douglas Gravel-Silverdale	8 0			7 2	4 7		4 2		1 6				5 0	0 9	0 5
Atchison Limestone	1 9		3 0			0 3							0 6		1 0
Arkansas City Gravel									1 6	2 3			0 5		0 4
Holliday Gravel				1 4			0 4			4 3			1 4		
American Rock Crusher (L S)										0 9	0 4	4 1	0 2	0 1	0 9
Neosho River Gravel				1 1									0 2		
Chat			1 1	3 8			11 0						3 8		0 3
Cement City Limestone	0 2			10 0	0 2	4 4	4 0	1 6	3 0				3 2	0 5	1 7
Vicinity Sources															
Kansas City Limestone			5 4	1 1	2 6	4 1		0 2		3 6			1 1	0 6	2 5
Topeka Limestone	7 9		10 5	6 3		3 2	2 3			0 4			4 4		3 8
Ottawa Limestone	2 8			0 3			4 2	0 6	3 3	8 0	1 6	1 4	3 9	0 5	1 2
Johnson-Miami County L S				3 6		3 1	3 1	4 3	1 2	7 9			3 4	1 2	0 9
Chanute Limestone	5 7		3 2	6 4	7 5	0 9				6 4			4 6	1 6	1 2
Ft Scott Limestone			1 1				1 9			4 5			1 6		0 3
Montgomery County L S			0 6		1 2	2 0				5 5			1 2	0 2	0 6
Lawrence Limestone	6 6	0 8	3 0	5 1		7 7	4 9						4 3	0 2	2 6
Dickinson Limestone	4 9												1 5		
Total By Conditions of Coarse Agg by Periods	45 6	3 6	50 8	49 4	16 2	34 4	57 0	9 7	33 3	68 3	4 1	27 6	54 5	7 9	37 6

* No disintegration See test for explanation

type of deterioration in less than 12 per cent of its extent. Similarly a pavement rated fair, has sustained damage of this type over 12 per cent and less than 50 per cent of its extent. Pavements rated poor have been subject to such failures either in excess of 50 per cent of their extent, or in severity greater than the No. 4 category or both cases may be and usually are present. These ratings are

period (1919–1924) over one quarter of the total pavements were paved with Joplin flint. This is mentioned to account for the larger percentage of commercial sources shown in this period. Subsequently with more local quarries opening up and mixed aggregate becoming more widely accepted, the vicinity sources predominate the next period Mixed aggregate accounted for nearly one quarter of the total and did not substantially vary from that point throughout the remaining periods. Beginning about 1930 the commercial sources became predominant and remain so to date.

Mixed aggregate pavements are not ordinarily subject to failures of the type described in group II (D-cracks) They suffer principally from the "map-cracking" type of failure previously described. Map-cracking is the subject of extensive research. Considerable information regarding this failure type is available from other sources. For the purposes of this report therefore the subsequent analysis of all data is based on the coarse aggregate pavements only Mixed aggregate is not seriously involved with the failure type under discussion here.

Table 5 shows the distribution of coarse aggregates from the various individual sources together with their condition rating as determined by the method outlined above. The data shown in Table 5 are the result of a critical analysis by an arbitrary method based on the relationship of the coarse aggregates involved with a particular failure type Numerous other influencing factors which affect the incidence and severity of this relationship are necessarily omitted in this discussion. It should also be borne in mind that this condition rating primarily describes the condition of the concrete rather than the pavement. Roughness, displacement, and poor riding conditions are present in many of the poorly rated pavements but not always, and similarly such conditions may also exist in a pavement rated here as good.

In addition it must be remembered that all of the coarse aggregates considered were found to be of satisfactory quality when examined at the time of construction according to the specifications in force at that time. These specifications varied from time to time, becoming more comprehensive and critical as the years passed Prior to 1930 specifications required little more than gradation control and a certain degree of cleanliness. Since that date requirements for durability, mix proportioning, water control, strength, and construction inspection, have been added from time to time as information became available and tests were developed to delineate these factors.

COMMERCIAL SOURCES

Lincoln sandstone or "quartzite" has been used in all four periods as a coarse aggregate for pavements Nearly 7 per cent of the pavements examined contained this material. Its record is universally good without regard to age. 3 1 per cent of the pavements included in period I were constructed with Lincoln sandstone and are rated "poor." Disintegration of the D-line type did not occur in these pavements as far as it was possible to determine by visual examination. They are so badly broken up and the surface obscured with repairs that they were rated "poor," for lack of positive evidence otherwise.

Bazaar gravel became an important source of coarse aggregate in the fourth period, accounting for 13.8 per cent of the total mileage constructed during this time, and 3.1 per cent of the total pavements surveyed. The slabs included in this source group are all more than five years old. (As previously mentioned this period is considered a five year construction period since very few pavements were laid subsequent to 1940) Based on the premises of this survey, Bazaar gravel pavements have been rated "poor" without exception. There are mitigating circumstances concerning this material which should be mentioned however, before too critical a conclusion is drawn from this service record. This is one of the few materials tabulated which does not have some service record over the whole period considered (1919–1945). All pavements containing this aggregate are on heavily traveled routes, subject to heavy loads, and they were constructed at a time when considerable experimenting with complicated joint devices, center strips and other "gadgets" were included in the pavement design. These factors are known to accelerate concrete disintegration, once it starts. Any exact conclusion concerning Bazaar gravel must therefore be reserved, pending the accumulation of more information over a longer period of time under conditions more nearly average. Nevertheless the record entered here for Bazaar gravel certainly indicates that it is a material which must be closely observed and controlled as to quality in the future.

Garnett limestone was used as a coarse aggregate in the first and the fourth periods. Its record is predominantly good. The 20-yr.

old pavements indicate that deterioration of limited extent and severity of the group II type may occur in concretes made from this material.

Joplin flint, a coarse aggregate not to be confused with flint chats, was used extensively in the first period, to a lesser extent in the second period, and not at all in subsequent periods. This material comes from a large area rather than an individual pit The material varies in quality from pit to pit, which may be a partial explanation why some flint pavements are still good after twenty years of service. In the main however the flint pavements are rated "poor," a ratio of about 1:4, good to poor.

Moline limestone has a service record extending over all periods. Over the years its record is predominantly poor, about 1:2. Prior to 1930 Moline limestone pavements are rated good. In the third period (1930–1934) they are excessively poor (1.3) in the final period they have a good to poor ratio of about 3:2. Although the information prior to 1930 is scant, it seems to indicate some change in the character of the material at about that time, possibly a change from hand to machine methods of production took place. This quarry is known to contain materials of varying quality from ledge to ledge in the quarry face. Production in recent years has been carried on by machine methods over the total quarry face. Selective quarrying in high quality ledges by hand methods in the past may have caused the difference between the records of the periods divided at 1930. Certainly the poor record of this material in relatively new pavements is a subject of grave concern and continuous observation and close quality control will be required in the future.

Silverdale-Douglas gravels are from sources now exhausted. They have a service record covering three periods from 1919 through 1934. The record is very good, 10:1, good to poor. The oldest pavements constructed with this material, comprising 8 per cent of the miles surveyed in period 1, are all rated "good" In period 2, all were either "good" or "fair" (about 2 1 good to fair) and in the third period about 2 5·1 good to poor This decline in quality with decreasing age of pavement may indicate that as the pit workings approached exhaustion, the quality of the material suffered. Continued observation of these pavements might be interesting in this connection, but unprofitable from other standpoints since little of this material remains.

The service record of Atchison limestone extends over the first two periods Pavements containing this material comprise only 1 6 per cent of the miles of pavement surveyed. Their record is poor in both periods, the second period having only pavements of "poor" rating. The information on this material is brief but it serves to indicate that this stone is of questionable quality, requiring further observation and close control if used in the future

Arkansas City gravel is a washed chert gravel from the Walnut river Its use in concrete pavements has been slight, only 0.9 per cent of total survey miles, during the last two time periods. Pavements over 10 yr. of age were rated "poor," those less than 10 yr. of age "good" If this brief record is representative of the action of this material, it may be concluded that serious trouble is to be expected after 10 years of service. However, the remarks concerning Bazaar gravel, in regard to other influences, also obtain here Any exact conclusion bearing on the quality and service record of Arkansas City gravel must be reserved, pending the accumulation of more detailed information and greater use of the material.

Holliday gravel is a washed, crushed, and graded chert gravel containing limestone, secured from a glacial pit near Holliday, Kansas. Its record, extending from 1925 to the present, is excellent All pavements constructed of this material were rated "good" Although this material has been used in only 1.4 per cent of the total coarse aggregate pavements surveyed, the good record throughout is considered indicative of future action of this material

The chert gravels, Bazaar, Arkansas City, Douglas-Silverdale, and Holliday, are four materials of varying character as indicated by the results of this survey. Holliday and Douglas-Silverdale gravels have given excellent service; Bazaar gravel has been rated "poor"; Arkansas City gravel is a material of questionable character not yet completely evaluated. The property or properties of these materials, apparently of similar character, which cause them to act in this manner is not yet known. This subject is at the present time the objective of a research project at our laboratory.

Limestone from the American Rock Crusher Company has not yet been used extensively in concrete pavements 1 2 per cent of the miles surveyed were pavements containing this material, all built in period IV, (1935–45), and prior to 1943. These slabs have a poor record, rating good to poor about 1·4 5 The remarks in reference to alleviating circumstances, made in connection with Bazaar gravel, also apply here. The fact that both of these materials, of good quality according to existing methods of test at the time of construction, suffer materially from the same type of disintegration after a relatively short service life, may indicate that the major source of trouble is something other than the aggregates. This is certainly a situation worthy of further investigation, and at the same time this aggregate's service record is such that it must be considered to be of questionable quality.

Neosho River gravel has been used in only one project representing 1.1 per cent of the miles surveyed in period II, and only 0 2 per cent of the survey miles. On this narrow basis its service record is rated "good," but that rating cannot be considered conclusive due to scarcity of information concerning this material. Neosho River gravel may be a potential supply of aggregate in the future and if such proves to be the case it will be necessary to study this material further. In passing, it is interesting to note that Neosho River gravel is a water borne material from the Flint hills, the same basic source as the Bazaar gravel, and possibly it should be judged to some extent with reference to the behavior of the Bazaar.

Chat is from the same general source as Joplin flint. Chat is a more finely ground material produced as an aggregate after numerous processes of milling and washing to remove lead and zinc ore 4 1 per cent of the coarse aggregate pavements examined were constructed using this material Chat pavements over 20 yr. of age were rated "poor," those from 11 to 20 years old were rated "good." Their service record compared to that of Joplin flint, is about three times as good as the flint Some clue to the differences in the behavior of these two types may be found in the relative sizes of the two materials and the treatment received by the chats in the milling processes. These factors are also the subject of laboratory research at this time.

Cement City limestone is produced in Missouri near Kansas City. It has been rather widely used, accounting for 5.4 per cent of the coarse aggregate pavements surveyed, and distributed over periods I, II, and III. Prior to 1930 it has a good record of service in regard to deterioration, good to poor ratio about 2 3:1 in period II Since 1930 the quality of pavements containing this material has declined, (a ratio of 4 3), while the overall ratio for all periods is about 2:1, good to poor This material occurs in both nodular and massive form in the quarry It is known that the nodular type material was rejected for use as an aggregate prior to 1929 or '30, since that time both types of material have been included in aggregate production. This circumstance may have some bearing on the character of the service received from this material during the various periods in which it is tabulated.

VICINITY SOURCES

Each vicinity source discussed hereafter is an area including several individual quarries or pits. It is realized that some variations in quality and type exist between these separate quarries. However, the physical properties and appearance of these materials is thought to be sufficiently similar to warrant grouping them as shown in Table 3 Each area is designated by the town or county in or near which the quarries are located.

Kansas City limestone has been used in pavements constructed in each of the four time divisions. While its overall record is poor (1.2 5 good to poor) it is significant that the rating of the pavements involved declines with increasing age. Disintegration has occurred in pavements of all ages but it is of considerably more extent in slabs built prior to 1930 It is apparent that concrete slabs built with this material are susceptible to this type of damage (D-cracks) after about 15 yr. of service.

Topeka limestone has a record similar to that of the Kansas City stone. Its overall record is about even between good and poor pavement miles It has been more extensively used (8 1 per cent of total miles) than any other vicinity sources, the greater part being in pavements over 15 yr. old. It is in these older pavements that serious deterioration is found. Age seems to be the governing factor in the frequency of occurrence and severity of the deterioration found in these slabs.

Ottawa limestone has been used in pavements in all time divisions. Its record for the total period is good, about 3.1, good to poor, but all of the pavements rated "poor" were constructed between 1930 and 1940. Those before 1930 are rated "good." Obviously there is some undesirable influence at work in pavements containing this material, other than age This situation is the reverse of that found in the Kansas City and Topeka stones and should certainly warrant further investigation of the quarries producing aggregates for pavements since 1930.

Johnson-Miami County limestone—This material served as coarse aggregate in pavements constructed in periods II, III, and IV. In peiod II, (16–20 yr. age) the pavements examined were about equally good and poor. In period III, deterioration was more moderate, 3 1 per cent good, 4.3 per cent fair, and 1 2 per cent poor, while in period IV, all were rated good, with an overall rating (1925–1945) about 3:1, good to poor. The situation here is similar to that of the first two vicinities mentioned, Kansas City and Topeka, a good record up to 15 yr. of age, and relatively serious deterioration after that point.

Chanute limestone pavements duplicate this same general condition although to a somewhat lesser extent These pavements appear to last about 5 yr. longer than the others from vicinity sources, before serious disintegration is found Only moderate failures were found in period II, none in periods III, or IV, and more "good" than "poor" in period I. Throughout the total period this material has a good record of service, rated about 4.1, good to poor

Fort Scott limestone was used on only 1 9 per cent of the total miles of coarse aggregate pavements surveyed It has a good record of service based on the information secured in this survey. Pavements over 20 yr of age were rated "poor," those less than 15 yr of age, "good," with no construction from this material during II (16–20 yr. of age)

Montgomery County limestone—These slabs again show the effects of age in relationship to deterioration more than any other factor. Slabs less than 10 yr. of age are good, over 15 yr. of age, fair or poor with no construction from this material during period III (11–15 yr old).

Lawrence limestone was used as a coarse aggregate for pavement in periods I, II, and III. Those built in period III, (1930–34) are rated "good," those in period II, (1925–29) show a good to poor ratio of about 1:1.5, while those in period I have better than two "good" to one "poor" pavement miles. With no regular progression here of deterioration with age it seems advisable to investigate the individual quarries used during each construction period in order to determine the differences, if any, and to use that information in subsequent pavement construction for which it is proposed to use these materials.

Dickinson County limestone—Pavements constructed from this aggregate are unique in that they are all over 20 yr. of age and all rated "good." Without doubt some property exists in the materials or in the construction of these slabs, or both, which works to prevent deterioration of the type investigated in this survey. These pavements are on heavy duty routes, in rolling county, subject to all the undesirable influences which affect pavement slabs. It seems highly desirable to attempt to discover and make use of this phantom characteristic if possible.

CEMENT CONTENT

As a part of the data secured from the construction files of each pavement project included in this survey, the yield cement factors (in bbl per cubic yard of concrete) of some projects were tabulated. This information is difficult to secure for projects constructed prior to 1930 and in some instances for projects built between 1930 and 1935 The distribution of the many brands of cement used in Kansas pavements was found to be so wide spread and complex that identification of the Group II type of failures here discussed, with each brand or type of cement was found to be impossible. Therefore an attempt was made to correlate this failure type with the quantity of cement in the slab Table 6 is the result of this investigation The information is derived from projects representing 49 per cent of the miles of coarse aggregate pavements included in this survey. Cement factors were divided into three groups; (1) Low, less than 1 36 bbl. per cu. yd , (2) Medium, 1.36 to 1 60 bbl. per cu. yd and (3) High, over 1 60 bbl. per cubic yard. Information covering only periods III and IV (1930–1945) was accessible Of the pavements so studied it was found that 30.3 per cent fell in the low group, 63 1 per cent in the medium group and 6 6 per cent in the high group. The slabs having high cement factors are those containing chat as a coarse aggregate. They represent a relatively small percentage of the total but since they are rated as "good" (see Table 5) in a large majority, the percentage of "good" pavement miles shown in Table 6 for the high cement content group must be considered a

TABLE 6

RATED PAVEMENT CONDITION VS. YIELD CEMENT FACTOR—PERCENTAGE OF SURVEY MILES

Period No.	III			IV			Total Time		
Period	1930 thru 1934, 11–15 yr			1935 thru 1945, 0–10 yr.			1930 thru 1945, 0–15 yr.		
Condition	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Yield Cement factor group, bbl cu yd									
Low—Below 1 36	0	0	0	72 3	5 8	21 9	72 3	5 8	21 9
Medium—1 36–1 60	50 2	12 2	37 6	71 3	0 8	27 9	56 2	9 0	34 8
High—Over 1 60	83 6	0	16 4	0	0	0	83 6	0	16 4

result of the deficiencies of the aggregate, rather than an indication of superiority due to high cement content

Aside from this condition, this information does not indicate that the quality of cement incorporated into a concrete pavement has any major influence in relationship to the type of failure upon which the rated condition is based (deterioration). No low cement factors were found in period III and no high cement factors in period IV. With the exception concerning the chat pavements in period III as noted, the data indicate only that the projects rated good, fair, or poor, compared to cement content, appear in the same ratio as when compared to the coarse aggregate involved. The influence of age is seen in the difference between the percentage of each class shown for the medium group, the only group in which data from both time periods is available.

OTHER FACTORS

The extent and severity of failures in concrete pavements is brought about through the influence of numerous factors. This opinion is derived from the study of numerous surveys and research projects of past years The analysis of the influence of one factor, such as the relationship between coarse aggregates and certain types of deterioration or failure, as discussed here, must always be tempered with consideration for other factors involved A few such influencing conditions which are known or believed to have considerable bearing on this subject will be mentioned.

Expansion joints, of various types and layouts have exerted an undesirable influence upon pavements in which they are installed. It is believed that the presence of load-transfer devices in expansion joints brings about excessive tensile stresses in areas adjacent to the joint, resulting in cracks This condition often progresses into deterioration of the D-line type, particularly in pavements containing questionable aggregates. Frequently it is impossible to determine which occurred first, the cracking or the deterioration

Heavy traffic is a contributing factor to progressive deterioration Cracking resulting from overloading, whatever the cause, is a starting point for disintegration, subsequently accelerated by the passage of cars and trucks

Subgrade type, pumping slabs, and drainage conditions are three interrelated factors which in their unfavorable aspects bring about conditions in pavement slabs which are very likely to develop into disintegration. Such points once started progress rapidly under the influence of traffic and weather. The rapidity with which disintegration progresses once it starts is indicated by the fact that in rating the slabs examined in this survey, based on group II failure types (see Table 5), very few were rated "fair." Either disintegration was slight or absent entirely, resulting in a "good" rating or it had progressed to a degree beyond the "fair" category to the "poor."

The year 1930 is repeatedly mentioned in the foregoing discussion in connection with the varied character of pavements built before and after that date It is certain that about that time several basic changes occurred in concrete materials and construction practices Burning temperatures of cement clinker were raised and improvements in slurry mixes were made. Finer grinding of cement was instituted about the same time. Paving equipment became larger and vibrators were introduced. Quarries were operated by machine rather than by hand; commercial aggregate sources were more widely used than vicinity sources All of those factors undoubtedly have been of influence in determining the quality and service-life of pavement slabs; some of course were beneficial and some detrimental

Construction and maintenance practices may exert a large influence upon the service-life of pavement slabs. Some details of construction such as poor consolidation around joints, dry mixes, harsh mixes, and inadequate inspection and control are contributory to eventual failure of the slab. Inadequate maintenance after cracks and joints have opened up and deterioration started, has allowed such conditions to develop and progress.

Excessive cracking and early deterioration of a pavement slab may be brought about through failure to provide the thickness of slab required by the original design of the pavement. Recently several pavement patching projects in Kansas have been inaugurated. Removal of the old slab at damaged sections has demonstrated in several widely separated projects that the design thickness was not present.

Still another factor of great influence, present at all times and at work in all pavements is the effect of age. Deterioration of concrete pavements as the years increase is plainly indicated by recapitulation of the data from this survey (see Tables 6 and 7) Analysis of the importance and extent of influence of other factors must always be considered with due allowance for the length of time each slab has served

SUMMARY

The pavement condition of some projects as rated in this survey may well be the subject of disagreement by many who read or hear this report However it should be borne in mind as previously stated that these ratings are primarily of concrete condition rather than slab condition In addition this rating is based on one set of conditions limited to one failure type. It is not intended to imply that the causes and effects of such failures are limited to the relationship between coarse aggregates and this failure type. It is intended to convey the thought that this particular relationship is highly significant and by studying it in detail, some partial solution to the total cause of the whole problem will be effected. Also it seems expedient at this point to reiterate that all of these materials complied with the requirements of the specifications for quality of aggregates in use at the time, which were no doubt considered sufficient to secure materials of satisfactory quality during the period of their use. A brief review of the character of the coarse aggregates tabulated in Table 5 will therefore be made with these facts in mind.

Lincoln sandstone and Moline limestone are two materials which definitely indicate that they have a large influence in the occurrence of the group II failure or D-lines Apparently the sandstone prevents such deterioration and the limestone creates and accelerates it. As an example of these conditions, U. S 40 near New Cambria in Saline County is outstanding. Here the slab was constructed in alternate sections using the two materials, due to production difficulties rather than design. Figure 1 shows a stretch of this road with Moline limestone pavement in the foreground, changing to Lincoln sandstone at the cross-road. Figure 2 is a close-up of the joint at the transition point between the two aggregates, Moline limestone on the right, Lincoln sandstone on the left. This pavement was built as one project and is all of the same age. The failure in the Moline stone at this location is a typical case for failure type No. 5. The influence of the character of the aggregates may be considered as governing in this situation as all other factors must be approximately equal in such a short distance.

Figure 1. Moline Limestone in Foreground, Changing to Lincoln Sandstone at Crossroads, Saline County near New Cambria

Figure 2. Close up of Figure 1. No. 5 Type Failure Moline Limestone Right, Lincoln Sandstone, Left

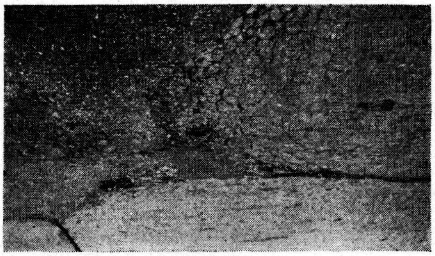

Figure 3. No. 5 Type Failure, 1929, Lyon Co., Joplin Flint

Joplin flint pavements are also examples of the great influence of the coarse aggregate in relationship to this failure type. These pavements are all over 15 yr. old. Figure 3 is a No. 5 failure in flint pavement on U. S. 50 in Lyon County. This joint has suffered serious displacement and has undergone extensive repairs, in addition to deterioration. Figure 4 shows a severe No. 5 failure involving both map-cracking and D-cracking in flint pavement on U. S. 54 in Butler County. On old U. S. 69 east of Arma in Crawford County, the pavement is almost entirely disintegrated although still in use. Figure 5 is a photograph of the conditions found on this road. This is a partial view of a No. 6 failure of considerable extent. Another case of equal severity is shown in Figure 6, a No. 6 failure of greater

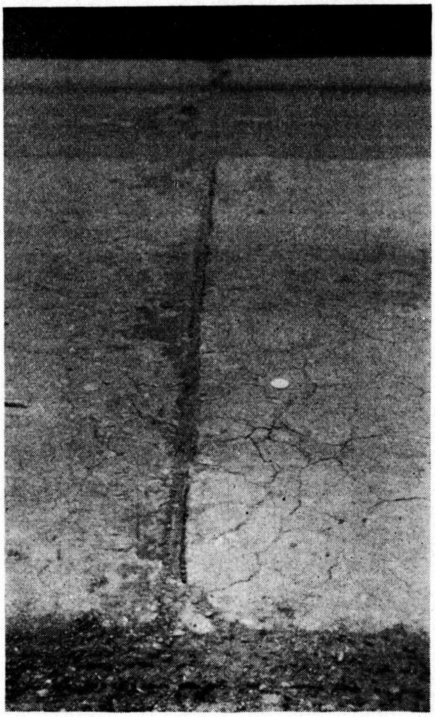

Figure 4. Hybrid Map Cracking and D Cracking, Patterns on No. 5 Joplin Flint, Butler County

extent than shown in the photograph, found in a flint pavement on U. S. 54 in Butler County. Examples of these conditions may also be found on U. S. 75 in Shawnee County and at other widely separated points. Joplin flint pavements account for 10.3 per cent of all the coarse aggregate slabs surveyed. It is no happenstance that 80 per cent of these miles of slab were rated "poor," and with full realization of the influence of all other factors bearing on concrete pavement failures, it is apparent that the coarse aggregate involved plays a leading part in the quality and service-life of a pavement.

Bazaar gravel pavements were rated "poor" in all Bazaar pavements examined. Figures 7 and 8 show why. Figure 7 is a full view and Figure 8 a close-up of a No. 5 failure typical of those found in the Bazaar gravel pavements. This one is on U. S. 50 in Marion County.

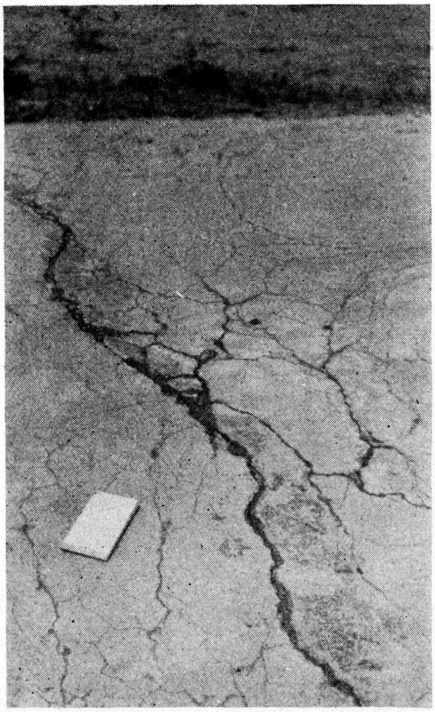

Figure 5. Joplin Flint Type of D Crack in Flint Aggregate, No. 6 Failure, 2 Miles E. of Arma, Crawford County

There are other accelerating factors at work here also but concrete disintegration is present to some degree in all the Bazaar pavements. Figure 9 is also a photograph of Bazaar gravel concrete badly disintegrated. Below the joint at the bottom of the picture is a slab constructed of mixed aggregate sweetened with Bazaar gravel which as yet is in excellent condition. All of these pavements are less than 11 and more than 5 yr. old. As previously discussed it seems well to reserve judgement on this material until more information is available.

Another material of questionable quality but which must be considered in the dark because of scanty information is the limestone from the American Rock Crusher Company. Figure 10 shows the development of a No. 4 failure in a 4-yr. old slab containing this material in Wyandotte County on U. S. 40. The west end of this slab is paved with Holliday gravel and is entirely clear of this type of

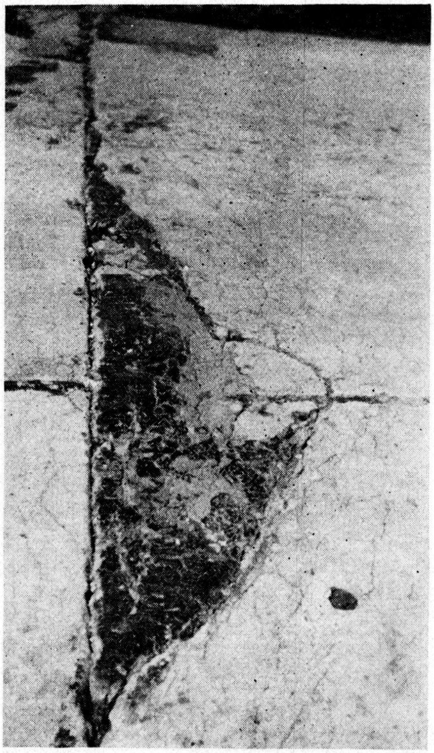

Figure 6. D Cracks in Flint (Webb City). Concrete Aggregate, Butler Co

trouble. Certainly at this point other factors of influence must be equal. Even the cement is the same. The only variable is the coarse aggregate.

Cement City limestone is a material with a variable record. It is better prior to 1930 than it is after 1930. Some reason for this condition has already been mentioned. Figures 11 and 12 are typical of the deterioration in the concrete made from this material. This slab was laid in 1931.

Figure 13 is a No. 5 failure found on U. S. 59 in Douglas County. This disintegration is in concrete from the Lawrence limestone group, a material with a record of very good service. This picture is of a slab 18 yr. old.

Figure 7. No. 5 Failure. Some concrete has been removed and patched with bituminous material. 1936 Marion County, Bazaar Gravel

Figure 8. Close-up of No. 13 Bazaar Gravel

Figure 14 is a photograph of a rather unusual failure, D-line disintegration in a mixed aggregate pavement constructed of material from the Blue River Valley. It may be found on U. S. 36 in Brown County east of Hiawatha. This failure is unique in that this type of deterioration does not ordinarily occur in mixed aggregates and this particular mixed aggregate is usually free from map-cracking.

These typical views of D-line disintegration are representative of a wide spread condition in concrete pavements in this state. Numerous other examples of contrasting service

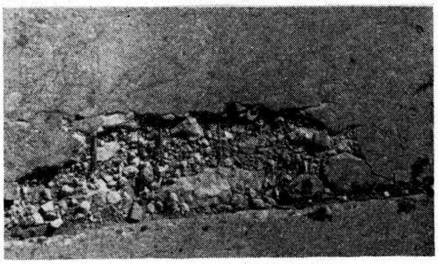

Figure 9. Bazaar Gravel. No. 5 Type Failure, Chase County

Figure 10. Wyandotte Co. D Cracks Well Developed in 4-yr. old Pavement. American Rock Crusher Limestone

records in adjacent slabs containing different coarse aggregates may be mentioned. U. S. 69 north and south of the Linn-Miami County line shows a distinct contrast between chat concrete and a deteriorating limestone concrete from the Johnson-Miami group. U. S. 24–40 east of Silver Lake and west to the Shawnee County line contrast an excellent 20-yr. old pavement containing a local stone from the Topeka group and a badly disintegrated pavement built with Moline limestone, now being patched and resurfaced, about 15 yr. old.

It seems futile to attempt to tabulate all of these coarse aggregates in the order of their susceptibility to disintegration of the type under discussion. In the commercial source group, Bazaar gravel, Moline limestone, Atchison limestone, Joplin flint, and American Rock Crusher limestone are materials which apparently are highly susceptible to this type of disintegration when incorporated into concrete pavements as coarse aggregates. Lincoln sandstone, Garnett limestone, Douglas-Silverdale gravel, Holliday gravel, and chat are materials in which such disintegration occurs to only a limited extent or not at all. Arkansas City gravel and Neosho River gravel are materials which may not yet be assigned to either of the above class until more information concerning them is obtained. Cement City limestone is a material of predominantly good record but of variable character.

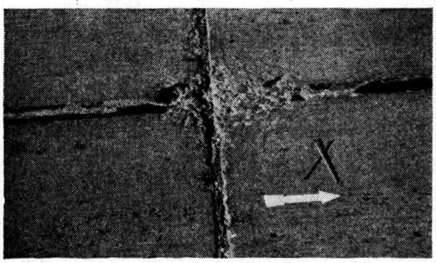

Figure 11. Type No. 4 Failure at Center Line of Expansion Joint, Johnson County, Cement City Limestone.

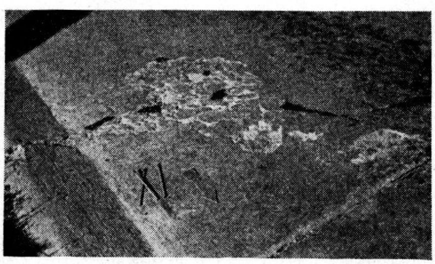

Figure 12. Type No. 5 Failure. Concrete has scaled from surface for area of 9 sq. ft. Johnson Company, Cement City Limestone.

Figure 13. No. 5 Failure, Complete Disintegration, Douglas County, Lawrence Limestone

All of the limestones from the vicinity sources were found to suffer from concrete deterioration to some degree, with the exception of the Dickinson County material. Kansas City limestone is the only source group with "poor" ratings predominating. All other vicinity source groups have more miles of pavement rated "good" than those rated "poor."

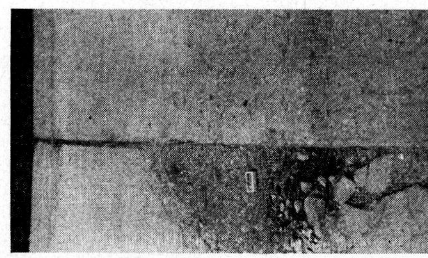

Figure 14. No. 4 Failure Developing into No. 5 Failure, Irving Gravel (B. River), Brown County

Table 7 is a recapitualtion of Table 6 by source groups. The vicinity sources consistently indicate a larger percentage of good pavements than do the commercial sources. In the commercial source group, period I, due to the large number of Joplin flint pavements included, the poor pavements exceed the good and fair slabs by about 7 per cent. In periods II, III and IV, the "good" slabs exceed the "poor" slabs to some degree in each case. In the total time period (1919–1945) good and fair slabs exceed the poor only by 7.6 per cent, a ratio of 1.3 to 1, good and fair to poor for the commercial group. The vicinity source groups have an overall rating of 26.0 per cent good, 4.3 per cent fair, 13.1 per cent poor, a ratio of 2.3 to 1, good and fair to poor, nearly twice that of the commercial source group. Analysis of the totals indicates the deterioration of all slabs as the years increase Period I, the oldest, is about equally divided between poor and good plus fair, about 1 to 1 This ratio gradually changes as the ages of the slabs decrease until in the youngest period (period IV, 1935–45) the ratio is 2 6 to 1, good and fair to poor. The ratio of good and fair to poor, for all coarse aggregate pavements examined is 1.7 to 1. Here is a clear indication of the combined effect of the influence of all factors which are contributory to the deterioration of a concrete slab that may be simply referred to as age To recapitulate briefly, these factors are weather, traffic load, subgrade and drainage conditions, quality of materials, thickness, design and installation of expansion joints and other appliances installed in the slab, and the influence of changing practices in design and construction over the years

TABLE 7

DISTRIBUTION OF COARSE AGGREGATES BY SOURCE GROUPS, CONDITION AND TIME PERIOD—PERCENTAGE OF SURVEY MILES

Period No	I			II			III			IV			Total Time		
Source	1919 thru 1924 (over 20 yr)			1925 thru 1929 (16-20 yr)			1930 thru 1934 (11-15 yr)			1935 thru 1945 (0–10 yr)			1919 thru 1945 (0–26 yr)		
Condition	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Commercial	17 7	2 8	27 0	26 6	4 9	13 4	40 6	4 6	28 8	32 0	2 5	26 2	28 5	3 6	24 5
Vicinity	27 9	0 8	23 8	22 8	11 3	21 0	16 4	5 1	4 5	36 3	1 6	1 4	26 0	4 3	13 1
Total	45 6	3 6	50 8	49 4	16 2	34 4	57 0	9 7	33 3	68 3	4 1	27 6	54 5	7 9	37 6

CONCLUDING REMARKS

All of the foregoing discussion has been in reference to damage and failure in concrete pavements in Kansas. It is easy to see the poor conditions and remember the location of rough slabs and the extent of failed areas It is not to be inferred however that concrete pavements have gone to rack and ruin in Kansas. Sixty to seventy per cent of the slabs built since 1930 are still in good condition Many pavements built before that date are also in good shape Pavements rated "fair" or "poor" in this report are not destroyed and many of them are not yet seriously damaged from the standpoint of loss of capacity to carry heavy loads, nor have they all suffered extensive displacement Many years of service can be secured from these slabs through adequate maintenance, repair, and resurfacing where necessary. The existence of deterioration in concrete slabs can be detected at an early stage and proper measures taken to retard its progress and perhaps through the acquisition of information such as presented here, eventually it can be eliminated.

Kansas experience with concrete pavements in the past 25 years indicates that pavements are subject to deterioration from the normal influences of age and service Obsolescence must be expected and provided for in maintenance programs and replacement budgets. Concrete pavements in Kansas constitute only about 15 per cent of the total mileage in the State Highway System, roughly one-fifth as much concrete as other types of hard surfaced roads. It follows therefore that in Kansas, experience with concrete slabs is limited and while some of them may not have served as well or as long as expected neither may it be concluded that the full potentialities of concrete pavements have been developed.

This survey was undertaken primarily to investigate the relationship between certain classes of pavement failures and the materials incorporated into the concrete, principally the aggregates Before this work was started however, it was known that many other factors were involved in the analysis of the causes of pavement failure. The limited investigation reported therefore assumes the character of a preliminary effort which reveals to some extent the complex nature of the whole problem and in a limited way, the extent and severity of damage already sustained by concrete pavements in this state.

An adequate investigation of the whole problem, the causes of concrete pavement failures and the development of preventive measures, will not be insured by a single survey nor by several unrelated efforts. A broad integrated program including field surveys, laboratory research, and close observation of developing conditions will be required.

A large part of such a program has already been initiated by the Kansas Highway Commission in cooperation with the Kansas State College Engineering Experiment Station and other interested agencies.

The fact that the aggregates used in pavement construction in Kansas were not performing as expected, has led to a review of the laboratory tests for durability of aggregates, and several research projects relating to this phase of the whole problem have been completed or are now being studied

An extensive investigation of the properties of flint chat aggregates in concrete has been completed and specifications prepared from the results of this research, to govern their use in the future.

A very complete study of "map-cracking," he failure type found in mixed-aggregate pavements, has been made.

Pavement pumping and its relationship to the sub-grade materials is the subject of a recently completed survey.

Several experimental pavement projects have been constructed in past years. They are the subject of continuous observation and study.

As the result of these various studies several innovations have been brought about in the present specifications for coarse aggregates for concrete Some limiting requirements for the maximum size of aggregates from individual sources have been developed as a result of a study of the freezing and thawing test in past years. Changes in the procedure of the freezing and thawing test have been made. These changes are expected to make this test more efficient in evaluating the quality of an aggregate and predicting its action in service as the principal component of portland cement concrete. New durability tests for mixed aggregates have been introduced as a result of the study of map-cracking in sand-gravel aggregates. Further study of research and experimental projects is expected to add to our store of knowledge concerning this problem. As more detailed information becomes available improvement in our specifications and test procedures for concrete aggregates will be brought about through these developments.

All of these investigations have contributed much valuable information toward the eventual solution of the main problem It seems essential to carry on work of the type mentioned and expand its scope to include other phases not yet examined. More complete records pertaining to earthwork and pavement construction are needed. Observations should be made and recorded, beginning during the construction of new highways and continued at frequent intervals throughout the service-life of the pavement. The development of more adequate tests for quality of materials which will accurately predict their performance in service is necessary. The accomplishment of such a program will require not only the cooperation of laboratory and research personnel but in addition must command the interest of materials producers, construction engineers and contractors, planners, designers, and maintenance engineers