Eight Years of Pulse Velocity Tests on Concrete Pavements in Kansas

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For the past eight years the Kansas Highway Commission has been investigating the changes in pulse velocity which occur with changes in concrete quality. A soniscope, as developed by the Hydro Electric Power Commission of Ontario, Canada, and the Portland Cement Association, has been used for making these tests.

Pulse velocity tests have been made regularly on eight experimental pavements which have been constructed in Kansas. Each of these test roads are made up of a number of test sections which contain concrete of varying composition. One such test road near McPherson, Kansas, is made up of 60 test sections which contain five different brands of cement along with several pozzolanic additives. Test sections in the other experimental pavements contain concrete which in some cases is air-entrained. Other variables included in these test sections are coarse and fine ground cement, different types of aggregate, and different methods of curing. The regular tests on these several test pavements have been made in an effort to establish a non-destructive method for studying changes in concrete quality which may not be apparent upon visual inspection.

Along with the regular velocity tests made on concrete pavements, pulse velocity determinations were also made periodically on test beams containing concrete comparable to that found in the several pavement test sections. These test specimens were then loaded in flexure to failure so that the modulus of rupture could be calculated. These velocity tests were then compared with the flexural strengths to see if changes in velocity could be associated with changes in modulus of rupture.

After studying the results of the large number of tests, several observations can be made. For the tests made on Kansas highway pavements, visual evidence of deterioration is obvious before this condition is reflected in a significant change in pulse velocity. Seasonal changes in pulse velocity tend to obscure velocity trends which otherwise might be significant. Although a small change in pulse velocity is often associated with a large change in flexural strength, no good relationship between the two is apparent at this time.

●FOR MANY YEARS investigators have been searching for a non-destructive test to determine concrete quality. In recent years attempts have been made to use resonant frequency and pulse velocity techniques for such tests. The resonant frequency method, which is only applicable to small, regularly shaped sections, has been used successfully. The pulse velocity method, which was originally developed to test large masses of concrete for deteriorated areas or cracks, has recently been used as a tool to check the general quality of concrete. For these tests a high pulse velocity has been thought to be indicative of good concrete quality and low velocity to indicate inferior quality.

In 1949 the Kansas Highway Commission embarked upon an accelerated program of concrete pavement research. A number of test roads were planned with test sections constructed of concrete of varying composition. Along with the conventional methods of evaluating the results of these roads, it was decided to use the soniscope to make pulse velocity determinations of the concrete in the pavement slabs.

One of these test roads, a 5-mi project near McPherson, Kansas, consists of 60 sections which contain various pozzolanic additions and five different brands of cement. Each combination of the above test variables is found in a section containing air-entrained concrete and in another section without air entrainment. The purpose of this project is to study the reactive expansion of concrete containing various pozzolanic additives in an attempt to reduce this expansion. This expansion, which is accompanied by map cracking, is thought to be a chemical reaction between the cement and the aggregate. Certain additives have been found to decrease expansion and make the cement and aggregate more compatible.

The second test road built in 1949 is located south of Topeka, on Highway US-75. This 8-mi test road is made up of 36 test sections which differ in the type of cement used, maximum size of aggregate and in the method of curing. The three types of cement used varied in composition and fineness. The purpose of this test road is to study the strength gaining qualities and durability of concrete containing these cements in an effort to establish which type of cement is superior.

In 1950 six other test roads were built in various locations in Kansas. The concrete in these test roads included these same three types of cement and in some cases was air-entrained. These roads were constructed to study the relative qualities of these several cement types under varying climatic conditions when used with different aggregates with and without air entrainment.

In the summer of 1949 the Kansas Highway Commission secured the loan of a soniscope which was used for the early pulse velocity tests on the McPherson and Topeka test roads. This soniscope had once been the property of the Portland Cement Association. The machine, while operating within rather wide accuracy limits, was difficult to use as a portable machine in the field.

In 1950 a new soniscope was built from plans obtained from Cheesman and Leslie of the Hydro Electric Power Commission of Ontario, Canada. This instrument is much smaller that the first model and easier to transport. The new soniscope is more sensitive and the transit time of the transmitted pulse can be more accurately determined. This machine has operated satisfactorily and has been used for all tests made since 1950.

TEST PROCEDURE

Pulse velocity tests have been made on these test roads at regular intervals at locations marked permanently in the slab. There are between 5 and 10 marked locations in each test section depending upon section length. This method of marking allows pulse velocity tests to be made each time at the same location. This rules out apparent velocity changes which might result if subsequent tests were made at slightly different locations on the pavement slabs.

All tests made on pavement slabs have been made with both of the transducers resting on the surface of the slab and spaced 4 ft apart. The transducer spacing is necessarily decreased when pulse velocity determinations are made on test beams. In order to insure that the transducer spacing remains constant, both transducers are mounted on a frame which facilitates the placing of the transducers on the slab. The trasducers are placed on the slab as a single unit which is then self-supporting. This method of transducer placement eliminates errors due to differences in transducer pressure, which change the effective path length of the transmitted pulse.

For the early tests, castor oil was used to lubricate the transducers to provide a good energy transfer between the transducer diaphragms and the surface of the concrete. For the past two years a carboxy methyl cellulose solution has been used for this purpose. No difference in transit time was noted for the different lubricants so long as sufficient quantities of both were used.

The pulse velocities as measured with the Kansas Highway Commission's soniscope are reproducible within one percent for path lengths of 3 ft or more. Little difficulty has been experienced in obtaining the pulse velocities, but the significance of these velocities is in doubt.

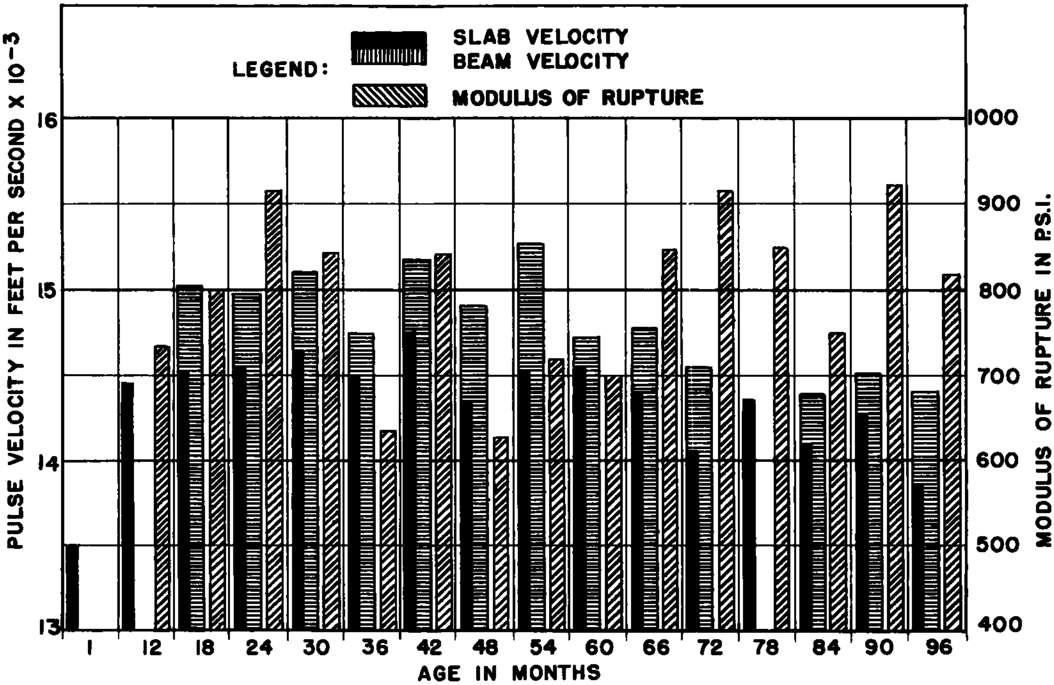

Figure 1. Correlation of pulse velocity and flexural strength on the McPherson Test Road.

RESULTS OF PULSE VELOCITY TESTS ON EXPERIMENTAL ROADS

Pulse velocity determinations have now been made regularly on these tests roads for a period of 8 yr. Each year some 1,400 separate pulse velocity determinations have been made on pavement slabs. Since 1951 about 250 determinations have been made on associated test beams each year prior to their being tested for modulus of rupture. For the past 2 yr all test beams have been soaked 24 hr prior to testing in an effort to obtain a standard moisture condition.

The average pulse velocities for all of the test sections and beams of the McPherson test road are plotted along with the modulus of rupture of the test beams in Figure 1. The tests plotted on the chart at ages 12, 24, 36, etc., were made in the fall. The pulse velocities have generally followed a seasonal pattern with the velocities being somewhat higher in the spring than in the fall. The pulse velocities for the test specimens averaged about 500 ft per sec higher than the velocities on the associated slab sections. The general velocity trend shows a slight decrease in both beam and slab pulse velocity.

Little correlation is visible between pulse velocities and the modulus of rupture. There have been large fluctuations in the modulus of rupture for the several test periods. The periodic or seasonal variation in both modulus of rupture and pulse velocity for the test beams has continued for the last four test periods shown in Figure 1 in spite of the 24-hr soaking interval. Large changes in modulus of rupture are accompanied, in most cases, by rather small changes in pulse velocity in the same direction. Small changes in modulus of rupture, however, may be associated with velocity changes in either direction.

Pulse velocities of three of the ten classes on concrete in the McPherson test road are shown in Table 1. The control sections for this project, designated as Class 1, are composed of concrete containing mixed aggregate with no pozzolanic material. This mixed aggregate is a river sand with a gradation factor of 3.58. Class 3FA concrete contains the same mixed aggregate with the addition of flyash as a pozzolan. Class 5 concrete contains this basic aggregate, 30 percent of which was replaced with crushed limestone.

TABLE 1

PULSE VELOCITIES BY CLASSES ON THE McPHERSON TEST ROAD[1]

	1 Mo	12 Mo	18 Mo	24 Mo	30 Mo	36 Mo	42 Mo	48 Mo	54 Mo	60 Mo	66 Mo	72 Mo	78 Mo.	84 Mo	90 Mo	96 Mo
Class 1																
Slab	13,500	14,660	14,590	14,640	14,560	14,490	14,610	14,330	14,530	14,410	14,210	13,960	14,150	13,880	14,010	13,670
Beams	--	--	15,140	15,150	15,140	14,540	14,680	14,300	14,580	13,810	14,030	13,760	--	13,480	13,720	13,320
Class 3 FA																
Slab	13,650	14,860	14,940	15,030	15,150	14,980	15,340	14,850	15,050	15,090	14,960	14,550	14,890	14,570	14,810	14,360
Beams	--	- --	15,380	15,350	15,520	15,290	15,740	15,400	15,900	15,280	15,340	15,280	--	14,910	15,020	15,080
Class 5																
Slab	14,070	14,970	15,030	15,030	15,190	15,100	15,340	14,850	15,030	14,990	14,850	14,580	14,840	14,580	14,680	14,320
Beams	--	--	15,420	15,450	15,510	15,220	15,610	15,540	15,790	15,300	15,160	15,110	--	14,970	14,910	14,850

[1] Pulse velocities in ft per sec

The pavement slabs in Class 1 show greater signs of deterioration than any of the other classes. Map cracking is extensive on these slabs and the test beams are also badly map cracked. This class has had a greater loss in pulse velocity than any of the other classes. Pulse velocities on some of the Class 1 test beams have decreased as much as 2,000 ft per sec. These beams, however, have deteriorated to such an extent that the received pulse on the soniscope in indefinite and the transit time is difficult to determine accurately. The pulse velocities for Class 3FA have averaged higher than any of the other classes. The flexural strength of the test beams in this class has also been high, but the condition of the slab is no better than some of the other classes which have lower velocities. The Class 5 concrete has the best service record in the field. This class has a high pulse velocity and very little map cracking on the pavement slab.

Pulse velocities for the Topeka test road along with the modulus of rupture of the test beams are plotted in Figure 2. Large fluctuations in pulse velocity and in modulus of rupture are not found for this test road. The seasonal pattern is not so apparent as on the McPherson test road. The pulse velocity of the slab has been in most cases somewhat higher than that of the beams.

No significant trends in velocity are apparent at this time for the Topeka test road. The pavement in this road is in generally good condition and little difference is visible between the several test sections. No close correlation is found between pulse velocity and modulus of rupture on the Topeka test road.

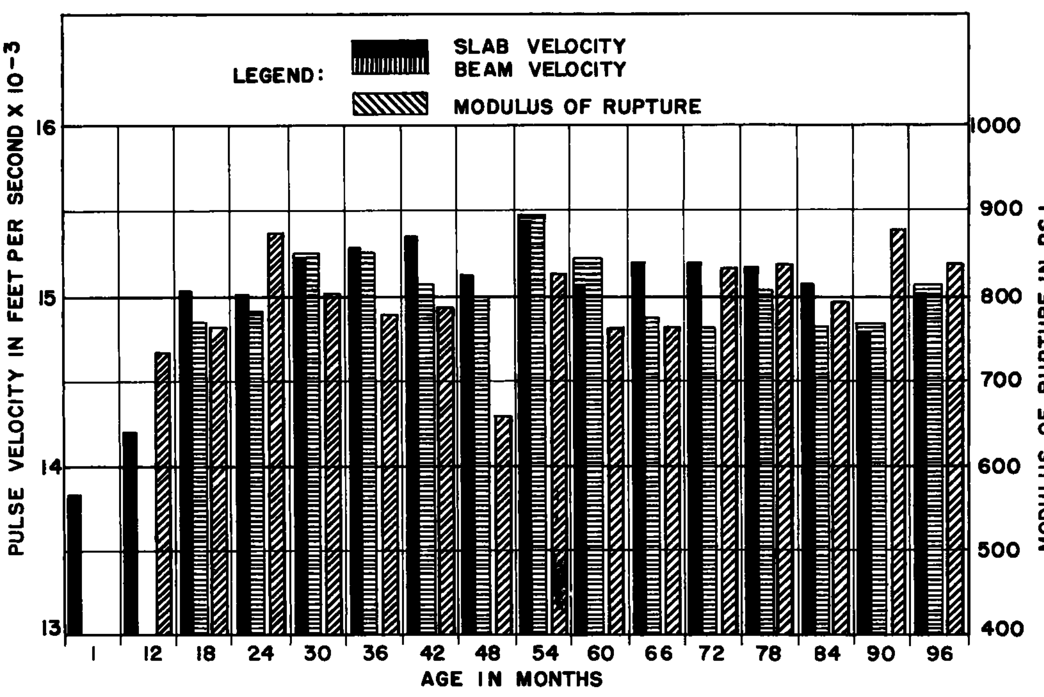

Figure 2. Correlation of pulse velocity and flexural strength on the Topeka Test Road.

The average pulse velocities for the six other test roads and the modulus of rupture of the test beams are plotted in Figure 3. The slab and beam velocities show decreasing trends, but no decrease in the modulus of rupture is in evidence. The pavement slabs are generally in good condition with few visible signs of deterioration at this time.

The test sections having air-entrained concrete have consistently had a pulse velocity 500 to 600 ft per sec lower than the same type of concrete without air entrainment.

OTHER PULSE VELOCITY INVESTIGATIONS

During the summer of 1951 a pulse velocity survey was made on a number of older concrete pavements. Between 20 and 40 separate velocity determinations were made on 48 projects which ranged in age from 1 to 29 yr. The average velocities for these projects fell between 13,800 and 15,900 ft per sec. No definite relationship between the age of the projects and the pulse velocity was apparent.

Map cracking was prevalent on a number of these pavements. In an effort to establish a relationship between pulse velocity and the degree of map cracking, test locations where map cracks were visible are classified as faint, medium, or severely map cracked. These averages are shown in Table 2 along with the number of test locations included in each category.

A decrease in sound velocity evidently accompanies map cracking, but the average difference was only about 500 ft per sec between severely map cracked areas and areas in the same projects where no map cracking was found. This apparent decrease in velocity may be due entirely to an increased path length because of the map cracks, and may not represent an actual change in velocity through the material. Changes in moisture content in the field were thought to be responsible for the seasonal changes in pulse velocity as found on the McPherson test project. In 1953 a group of thirty-six 3- by 4- by 16-in. test beams, which were cast at the time the test roads were built, were used for making moisture tests. These beams were soaked in water for six days and pulse velocity determinations were made. The beams were then dried in an oven at 125 F for 7 days. After the beams had cooled to room temperature, pulse velocity measurements were again made.

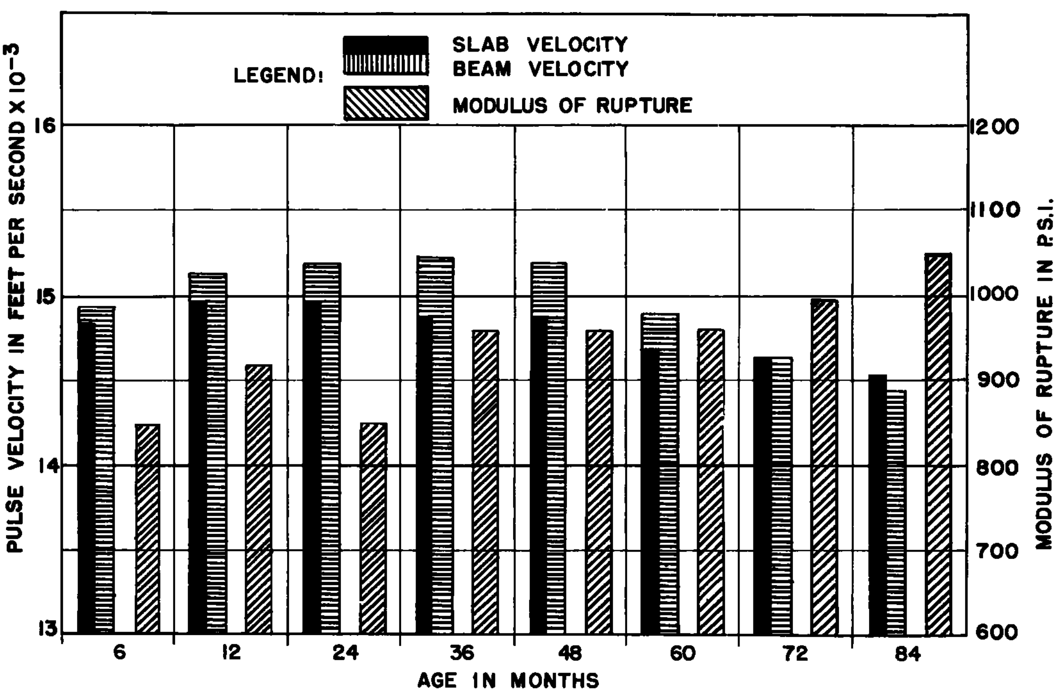

Figure 3. Correlation of pulse velocity and flexural strength on other Kansas Test Roads.

TABLE 2

Map-Cracking Category	Number of Determinations	Average Velocity ft per sec
None	155	14,445
Faint	109	14,300
Medium	64	14,265
Severe	53	13,975

The average velocity for the test beams in the saturated condition was 16,780 ft per sec. In the dry condition, the velocity was 15,760 ft per sec. Between the two tests the specimens had lost an average of 1.2 percent of their weight due to loss of moisture, and the pulse velocity decreased 6.1 percent. This change in pulse velocity due to a change in moisture content indicates that much of the seasonal variation found on the several test roads may be due to changes in concrete moisture.

In an attempt to establish in what manner the pulse velocity varies as an area of visible deterioration is approached, a number of special velocity investigations were made. Special emphasis was placed on areas and joints where considerable "D" cracking was evident. Successive readings were taken in the vicinity of such discontinuities so that velocity patterns could be established. The pulse velocity was expected to decrease substantially as the transducers were placed successively closer to a deteriorated area; this, however, was not the case. In a few instances there was a small decrease in velocity, 200 to 300 ft per sec, as a deteriorated spot was approached, but no pronounced decrease was noted until the transducers were actually resting on a cracked or disintegrated area of concrete. If this deterioration was of a nature that the concrete was no longer a continuous medium, a definite transit time could not be determined and the pulse velocity became meaningless.

CONCLUSIONS

1. For all tests made on concrete pavements in Kansas, visible signs of distress have been apparent before significant changes in pulse velocity have indicated this deterioration.
2. Changes in moisture content of concrete slabs apparently account for a seasonal variation in pulse velocity. These changes vary in magnitude with the season and tend to disguise pulse velocity trends which otherwise might be obvious.
3. Small decreases in velocity have been found on concrete pavements in deteriorated areas. In most cases, however, if the deterioration is pronounced the transit time cannot be accurately measured and no true velocity can be calculated. The apparent decrease in velocity in disintegrated areas seems to be due to a longer path length for the transmitted pulse rather than to a decrease in the modulus of elasticity.
4. Although changes in pulse velocity and changes in modulus of rupture correlate in a general way, no close relationship between the two seems to exist.

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