Air Content and Permeability of PCC Pavements: 1909 to 2006

Final Report
For
MLR-05-02

March 2007

Highway Division

Iowa Department Of Transportation

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March 2007

TECHNICAL REPORT TITLE PAGE

1. REPORT NO.

MLR-05-02

2. REPORT DATE

March 2006

3. TITLE AND SUBTITLE

Air Content and Permeability of PCC Pavements: 1909 to 2006

4. TYPE OF REPORT & PERIOD COVERED

Final Report, March 2007

5. AUTHOR(S)

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7. ACKNOWLEDGMENT OF COOPERATING ORGANIZATIONS/INDIVIDUALS

MARL Laboratory Iowa State University

8. ABSTRACT

Portland cement concrete pavements have given excellent service history for Iowa. Many of these pavements placed during the 1920's and 1930's are still in service today.

Many factors go in to achieve a long term durable concrete pavement. Probably the most important is the durability of the aggregate. Until the 1930's, pit run gravel was the most predominant aggregate used. Many of these gravels provided long term performance and their durability is dependent upon the carbonate fraction of the gravel.

Later, limestone (calcium carbonate) and dolomite (calcium, magnesium carbonate) sources were mined across Iowa. The durability of these carbonate aggregates is largely dependent upon the pore system which can cause freeze thaw problems known as D-cracking, which was a problem with some sources during the 1960's. Also, some of these carbonate aggregates are also susceptible to deterioration from deicing salts. Geologists have identified the major components that affect the durability of these carbonate aggregates and sources are tested to ensure long term performance in Portland cement concrete.

Air entrainment was originally put in concrete to improve scaling resistance. It is well known that air entrainment is required to provide freeze thaw protection in concrete pavements today. In Iowa, air entrainment was not introduced in concrete pavements until 1952. This research investigates properties that made older concrete pavements durable without air entrainment.

9. KEY WORDS

PCC Durability
Air Content
Permeability

10. NO. OF PAGES

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Introduction

Portland cement concrete pavements have given excellent service history for Iowa. Many of these pavements placed during the 1920's and 1930's are still in service today.

Many factors go in to achieve a long term durable concrete pavement. Probably the most important is the durability of the aggregate. Until the 1930's, pit run gravel was the most predominant aggregate used. Many of these gravels provided long term performance and their durability is dependent upon the carbonate fraction of the gravel.

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Air entrainment was originally put in concrete to improve scaling resistance. It is well known that air entrainment is required to provide freeze thaw protection in concrete pavements today. In Iowa, air entrainment was not introduced in concrete pavements until 1952. This research will investigate properties that made older concrete pavements durable without air entrainment.

Objective

The objective of this research is to evaluate various aspects, such as permeability and air entrainment, in concrete pavements of various ages and their affect on durability. Also, the changes in cement chemistry over the last century may give some insight into the potential impact on permeability.

Project Sites

A variety of paving project across the state were surveyed. The projects selected were full depth PCC pavements constructed between 1909 and 2006. Newer pavements were selected to evaluate the impact of blended cements on permeability. As of early 2005, all of the pavements were in service without an overlay. Table 1 contains the project information. Pictures of most of the pavements and cores may be found in the Appendix.

Table 1 - List of Pavements Investigated

County	Year	Location	Fine Agg	Coarse Agg	Cement
Mahaska	1909	Eddyville Cemetary Rd	Eddyville	Eddyville Gravel	n/a
Woodbury	1921	Old 20 E of Sioux City	Correctionville	Correctionville Gravel	Marquette Northwestern
Wapello	1929	Old 63 S of Ottumwa	Ottumwa	Dewey Stone	Marquette Atlas
Monona	1938	IA 175 MP 8.7 to 14.4	Correctionville	Correctionville Gravel	Ash Grove
Pocahontas	1946	IA 15 MP 0 to 5.5	Sacton	Sacton Gravel	Hawkeye
Greene	1955	US 30 MP 94.5 to 99.1	Sprague	Sprague Gravel	Northwestern Penn Dixie
Marshall	1963	US 30 MP 172.2 to 179.9	Clemons	Ferguson Stone	Dewey I Lehigh I
Hamilton	1975	US 20 MP 141.5 to 149.5	Sturtz	Moberly Mine	Marquette Lehigh I
Boone	1980	IA 17 MP 21.6 to 32.7	Christensen	Sturtz Gravel	Northwestern I Penn Dixie I
Story	1992	US 30 MP 151.9 to 156.8	Christensen	Ames Mine	Ash Grove 15% C fly ash
Linn	1997	US 151 MP 33.6 to 36.6	Ivanhoe	Bowser Stone	Holcim IS(35) 10% C fly ash
Jones	2002	US 151	Anamosa	Stone City	Lafarge IS(20) 20% C fly ash
Fremont	2006	IA 2	Oreapolis #8	Weeping Water	Ash Grove IP(25) 20% C fly ash

Specification History

During the time period of the pavements under this study, many changes have occurred over the years with concrete pavement specifications. The concrete specifications history may be found in MLR-07-01.

Air Entrainment

Air entrainment was originally introduced in the 1930's as a method to reduce scaling due to freezing and thawing. The pavement surface indicates slight scaling on pavements placed prior to the requirement of air entrainment, as shown in Figure 1.

Figure 1- Surface of core from old US 20 Woodbury Co. (1921)

Air entrainment was not introduced in Iowa until 1952. In 1995, based on low air contents discovered in pavements exhibiting early deterioration, the plastic air content was increased to 7 ±1% to compensate for excessive air loss. In 2000, air loss through the paver was determined and the plastic air content became 6 + Air Loss with a tolerance of plus 1.5 and minus 1%. The air content specifications are described in Table 2.

Table 2 - Air Entrainment Specification Changes

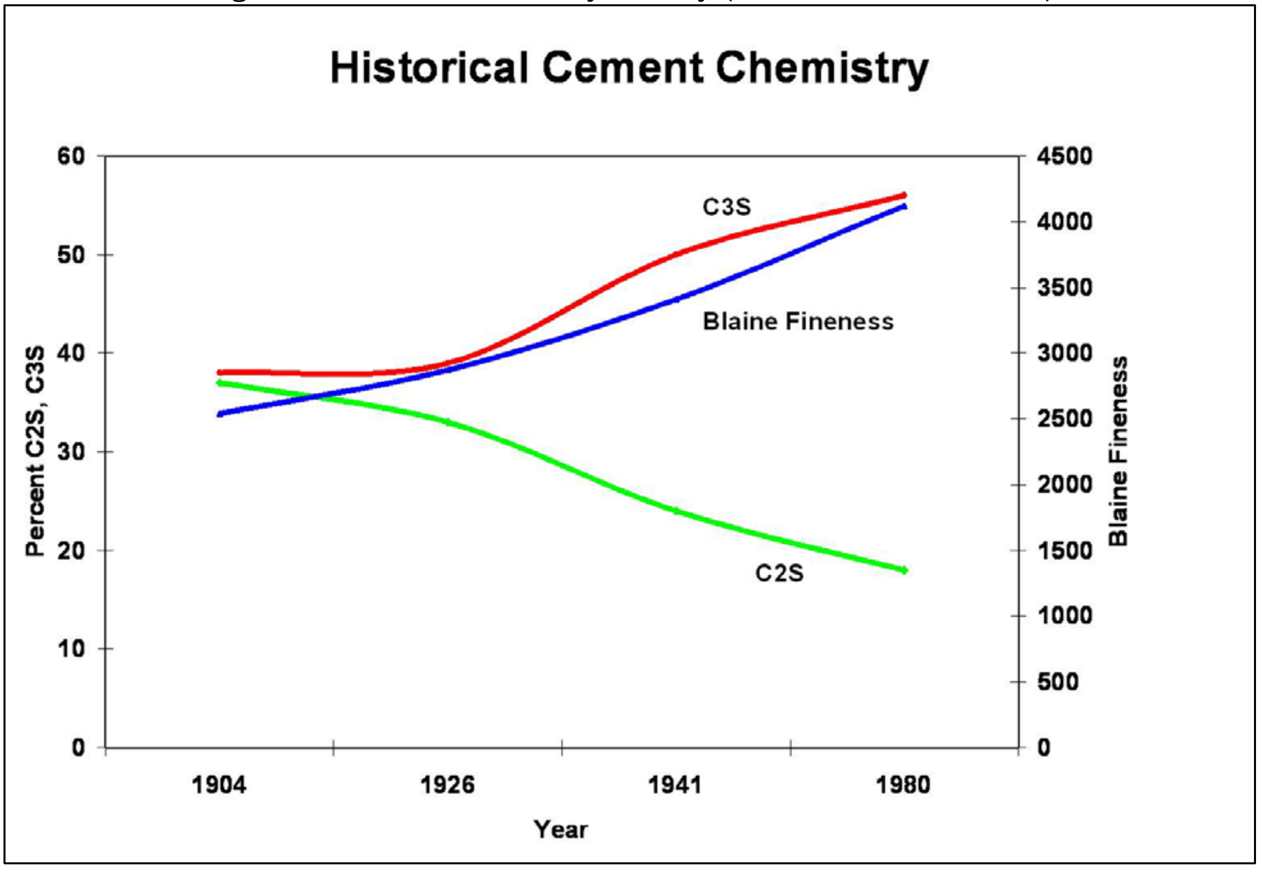
Year	Specification
1952	3 to 5% 5 to 7% Class V gravel
1956	4 to 6% 5 to 7% Class V gravel
1960	5 to 7%
1995	7±1%
2000	6 + Air loss through paver +1.5% & -1%

Cement Chemistry

Cement chemistry has changed dramatically over the past 100 years[1]. Accelerated construction schedules have demanded concrete with faster strength gain. Cements produced in the first half of the 1900's were higher in dicalcium silicate (C_2S), which is responsible for long term strength gain. Modern cements produced in later years were higher in tricalcium silicate (C_3S), which is responsible for faster strength gain. The changes in cement chemistry and fineness are noted in Figure 2.

An increased demand for increased rate of strength gain has an influence on the durability of concrete for the long term. It has been well documented the poor performance of concrete pavements when using fast track type mixes with Type III cements. Increasing the strength gain causes coarse CSH development, larger capillaries and thus increased permeability, and potential increase in shrinkage.

Figure 2 - Cement Chemistry History (C_2S, C_3S, and Fineness)



Testing

Three cores were obtained from each of the project sites. A 3/8" slice was sawed from near the top and bottom of the cores. The slices were polished for hardened air testing in the scanning electron microscope (SEM). A 2 inch slice was removed from the remainder of the core for rapid chloride permeability.

Hardened Air Content

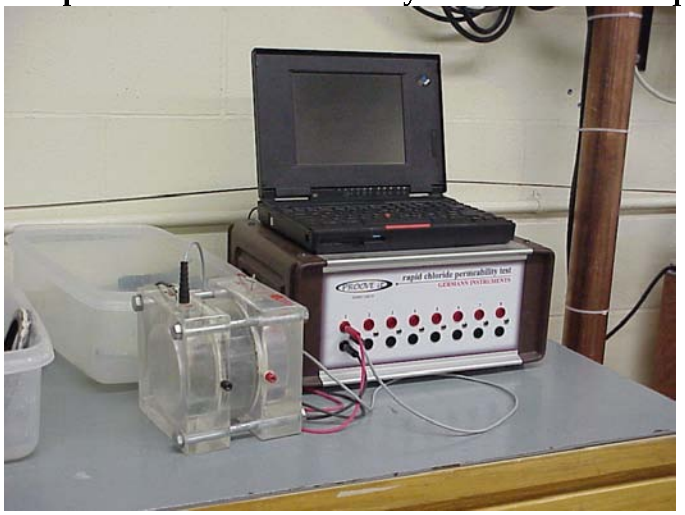
The SEM investigation was performed at the MARL laboratory at Iowa State University using the Hitachi S-2460N low vacuum SEM. The SEM was used to evaluate the air void distribution as well as the total air content in the top and bottom of the cores. To perform air void analysis, a total of 20 images are collected and saved. An image analysis program was then used to determine air void size and distribution. This method[2] is similar to the ASTM C 457 method, except bubble sizes are sorted by diameter as opposed to chord lengths.

Rapid Chloride Permeability

Two core slices were tested in the rapid chloride permeability apparatus in accordance with AASHTO T277. The rapid chloride permeability test gives an indication of permeability by electrical conductivity. The higher the resistance tested the lower the indicated permeability. Thus, the test is not a true measure of permeability. The data will be used as a comparison relative to each other. The cores were tested in as received condition.

Figure 3 - Hitachi S-2460N SEM

Figure 4 - Rapid Chloride Permeability Indication Test Equipment



Results

SEM Image Analysis Air Content

The results for concrete air content, mortar air content, and spacing factor are shown in figures 5 through 7. As expected the air contents prior to introduction of air entrainment are less than three percent, although these pavements have exhibited long term durability.

However, research[3] of Iowa pavements placed in the mid 1980's to mid 1990's exhibiting severe deterioration indicted low air contents, less than 4.5%, and poor spacing factors, greater than 0.008 in (0.20 mm) as a cause for deterioration. ASTM C 457 indicates the spacing factor should be in the range of 0.1 to 0.2 mm and specific surface in the range of 24 to 43 mm^{-1}. ASTM C457 also recommends a maximum spacing factor of 0.2 mm for moderate exposure to freezing and thawing and should be lower if exposed to severe freezing and thawing with deicing chemicals.

Figure 5 - Concrete Air Content

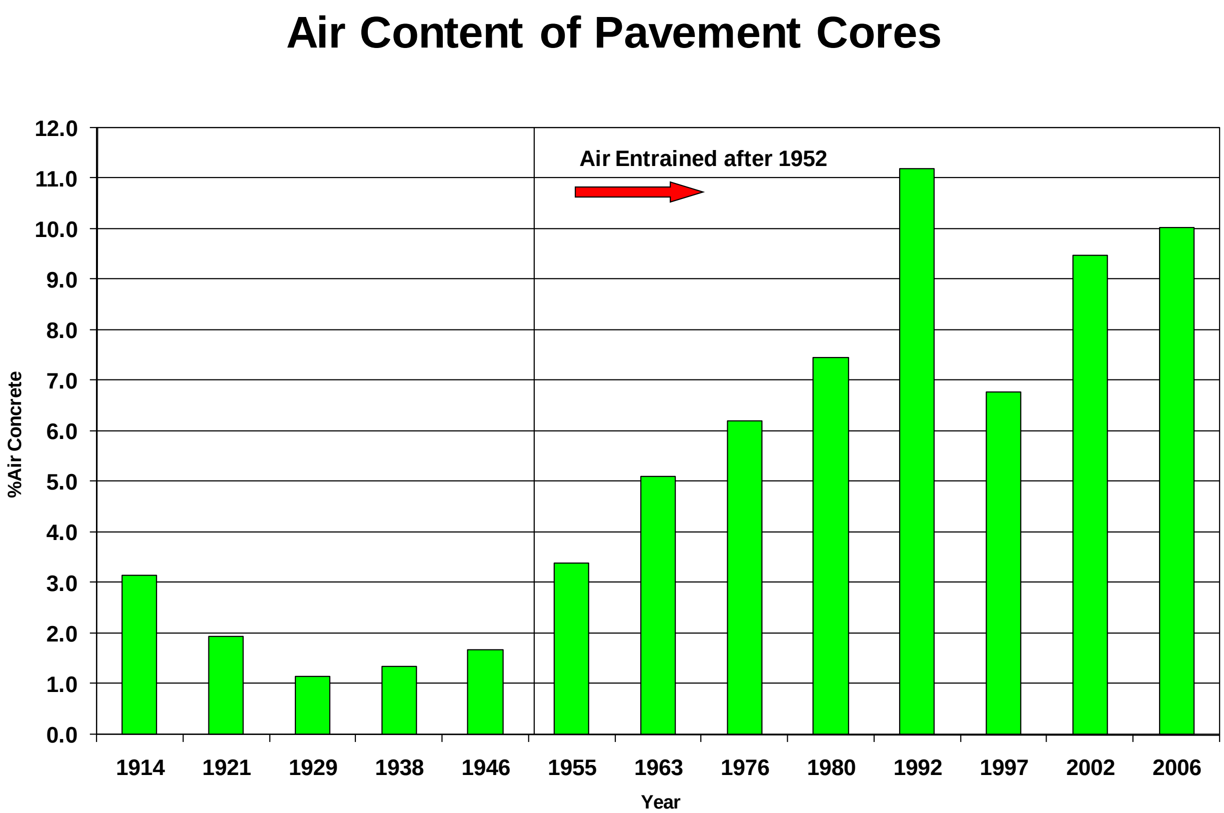


Figure 6 - Mortar Air Content

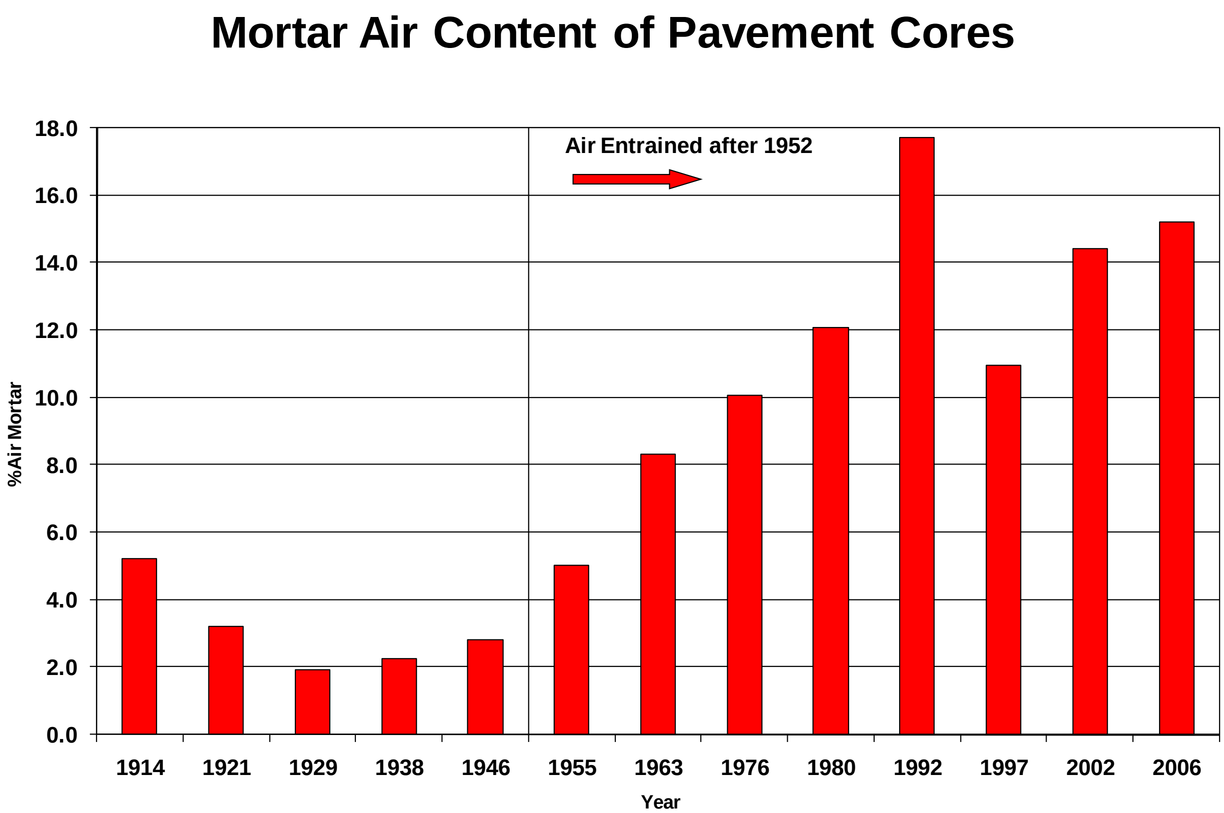
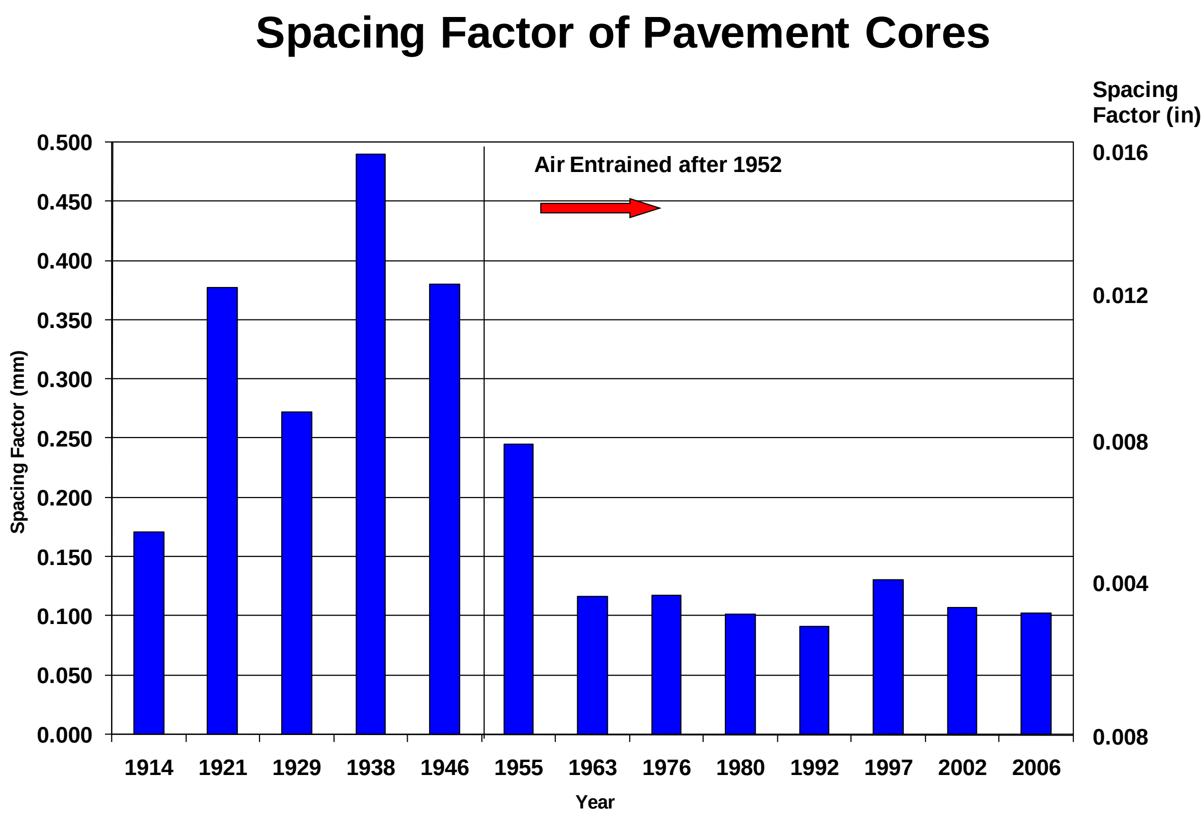


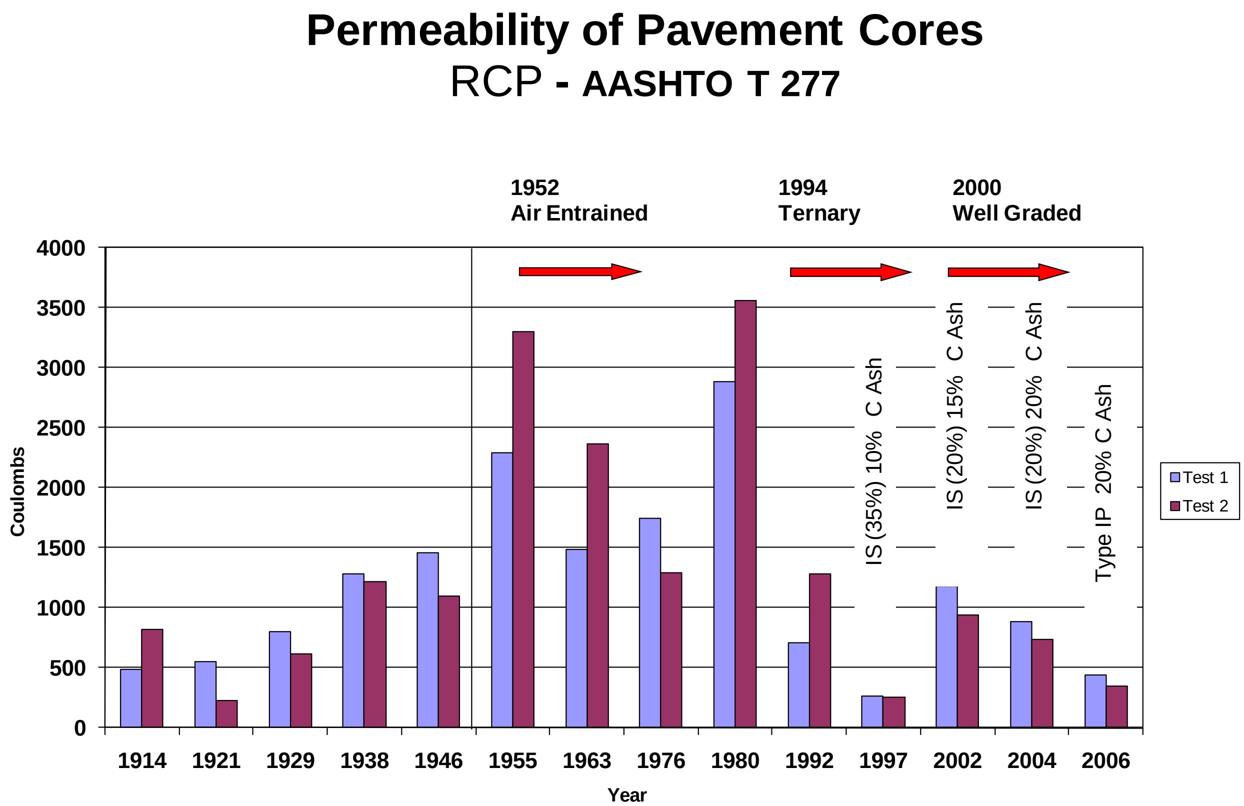
Figure 7 - Air Spacing Factor



Rapid Chloride Permeability Testing

The results of the rapid chloride permeability testing are found in Figure 8. Results indicate the older pavements, prior to the 1950's, are very low. There is an increase in permeability indicated after 1950. Use of supplementary cementitious materials, such as slag and fly ash, has shown a decrease in the indicated permeability.

Figure 8 - Rapid Chloride Permeability Results



Discussion

The air content of older pavements prior to the requirement for air entrainment is less than 3 percent. The permeability of these older pavements is fairly low compared to those built between 1955 and 1980. These pavements were durable as shown by their performance in 2005. Perhaps, the cements with high C2S resulted in lower long term permeability. It should also be noted that curing during this time was typically one day of wet burlap curing followed by six days of wet earth curing.

Pavements built between 1986 and 1994 that exhibit early deterioration had air contents less than 4.5%. Permeability results of those pavements are higher than those built before the 1950's. As permeability increased, perhaps the need for air entrainment for freeze thaw durability also increased.

The pavements built with ternary combinations of blended cements and Class C fly ash indicated permeability results as low as the older pavements. In theory, these pavements should exhibit long term durability.

Summary

The following is a brief summary of the results:

- The air content for projects placed prior to the requirement for air entrainment in 1952 is less than 3%
- Air contents increased as specification limits increased.
- The indicated permeability of older pavements is very low.
- The permeability of pavements utilizing a Shilstone type gradation and supplementary cementitious materials, such as slag and fly ash, can reduce indicated permeability to the level of older pavements.

Conclusions and Recommendations

Utilizing concrete with low permeability increases the chances of a pavement with long term durability. Use of Shilstone gradation and slag and fly ash reduces permeability to very low values. The Iowa Department of Transportation should continue to promote the use of well graded aggregates and use of supplementary cementitious materials.

Air entrainment increases freeze thaw resistance of modern concrete. It is not clear if the permeability of the older pavements is so low that air entrainment is not required to reduce susceptibility to freezing and thawing. Air entrainment should continue to be utilized regardless of indicated permeability of modern concrete pavements.

Barring any constructibility problems, use of Shilstone gradation, supplementary cementitious materials, and air entrainment should produce long term durable concrete pavements.

Acknowledgements

The authors would like to thank the Warren Strazheim, Jerry Ammenson, and Scott Schlorholtz of the MARL laboratory at Iowa State University for their efforts with the SEM and image analysis work. Also, thanks to the Cement and Concrete laboratory for their work on rapid chloride permeability testing.

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Appendix

Appendix 1 - Eddyville Cemetary Rd (1909)

Appendix 2- Eddyville pavement core

Appendix 3 - Old US 20 Woodbury Co (1921)

Appendix 4 - Woodbury old US 20 pavement core

Appendix 5 - IA 175 Monona Co. (1938)

Appendix 6 - Monona IA 175 pavement core


Appendix 7 - US 30 Greene/Carroll Co. (1955)


Appendix 8 - Greene US 30 pavement core

Appendix 9 - US 30 Marshall/Story Co. (1963)

Appendix 10 - Marshall US 30 pavement core

Appendix 11 - US 20 Webster Co. (1976)

Appendix 12 - Webster US 20 pavement core

Appendix 13 - IA 17 Boone Co. (1980)

Appendix 14 - US 30 Story Co. (1995)

Appendix 15 - US 151 Linn Co. (1997)