

100 Years of Concrete Pavement In Iowa

Final Report
For
MLR-07-01

March 2009

Highway Division



**Iowa Department
Of Transportation**

100 Years of Concrete Pavements In Iowa

Final Report
for
MLR-07-01

By
Todd D. Hanson
PCC Engineer
515-239-1226
Fax: 515-239-1092

Office of Materials
Highway Division
Iowa Department of Transportation
Ames, Iowa 50010

March 2009

TECHNICAL REPORT TITLE PAGE

1. REPORT NO.

MLR-07-01

2. REPORT DATE

March 2009

3. TITLE AND SUBTITLE

100 Years of Concrete Pavements in Iowa

4. TYPE OF REPORT & PERIOD COVERED

Final Report, March 2009

5. AUTHOR(S)

Todd D. Hanson
PCC Engineer

6. PERFORMING ORGANIZATION ADDRESS

Iowa Department of Transportation
Office of Materials
800 Lincoln Way
Ames, Iowa 50010

7. ACKNOWLEDGMENT OF COOPERATING ORGANIZATIONS/INDIVIDUALS

8. ABSTRACT

Portland cement concrete (PCC) pavements have given excellent service history for Iowa. The first concrete pavement was placed in Le Mars in 1904 and was in service until 1968. The Eddyville Cemetery Road placed in 1909 is still in service today. Many other pavements placed during the 1920s and 1930s are still in service today.

The objective of this report is to document various changes in specifications, pavement design and equipment for PCC paving from the early 1900s to present. This includes changes that were made to the specification book and supplemental specifications. Where possible, information is given as a basis for the change in specifications.

9. KEY WORDS

Portland Cement Concrete
PCC pavement
Specifications

10. NO. OF PAGES

89

Table of Contents

Introduction	1
Objective	2
Specification history	2
Grading, subgrades and subbases.....	2
Aggregates.....	5
Mix design	11
Materials.....	13
Concrete batching	15
Concrete placement	21
The slip form paver.....	24
Vibration	29
Finishing and texture	32
Curing.....	35
Opening time and strength	39
Jointing and sawing.....	39
Pavement smoothness.....	48
Pavement thickness	51
Pavement design.....	52
Interstate pavement design	55
Concrete overlays	58
Summary.....	60
Acknowledgements and credits.....	64
List of Iowa Concrete Pavements Built 1922 and Earlier.....	65
Chronological list of Iowa DOT PCC research	67
Appendices	73
References.....	89

DISCLAIMER

The contents of this report reflect the views of the author(s) and do not necessarily reflect the official views or policy of the Iowa Department of Transportation. This report does not constitute a standard, specification or regulation.

Introduction

Portland cement concrete (PCC) pavements have given excellent service history for Iowa. The first concrete pavement was placed in Le Mars in 1904 and was in service until 1968. The Eddyville Cemetery Road placed in 1909 is still in service today. Many other pavements placed during the 1920s and 1930s are still in service today.



Figure 1 Le Mars city street built 1904 - picture 1950s



Figure 2 - Eddyville Cemetery Road built 1909 - picture 2005

Objective

The objective of this report is to document various changes in specifications, pavement design and equipment for PCC paving from the early 1900s to present. This includes changes that were made to the specification book and supplemental specifications. Where possible, information is given as a basis for the change in specifications.

Specification history

The brief summary of specification changes include aggregates, materials and mix design, curing and opening, smoothness and thickness, finishing and texture, and equipment. When the date of the change was by either a supplemental specification (SS) or the biannual general supplemental specification (GS) update, it is noted in bold by the respective change. The summary is located in Table 1 of the Appendix.

Grading, subgrades and subbases

Before the placement of a concrete pavement can begin, a well compacted subgrade of uniform density is required. Prior to the 1960s, all concrete pavements were placed on natural subgrade. The subgrade was required to be constructed to a uniform density and width plus one foot. Sprinkling and wetting of the finished subgrade was required to ensure reasonable moisture content at time of placement.



Figure 3 – Subgrade trimmer and template – Polk County 1926



Figure 4 – Modern subgrade trimmer

In order to prevent moisture loss from the pavement, bituminous paper, lapped not less than 4 inches, was required on the subgrade. In 1960, plastic sheet, lapped not less than 12 inches, was also added as an option. In 1964, natural subgrade was required to be uniformly moist, but not muddy, to a depth of not less than 1 inch, or be covered with bituminous paper or plastic film.



Figure 5 - Placing tar paper on subgrade - Story County 1926



Figure 6 - Plastic sheet placed on subgrade behind Iowa Special paver – Lyon County 1977

The first sections of interstate pavements from 1958 to 1967 were placed on a granular subbase (GSB) layer to aid in drainage under the pavement. As sections of the interstate began to be replaced, there were concerns with what to do with the old concrete pavement. The old concrete was crushed, screened and placed as a granular subbase (GSB). In 1985, the first section of recycled concrete utilized as granular subbase (GSB) was placed in Pottawattamie County on I-80 eastbound from milepost 28 to milepost 35.

Recycling concrete pavement into granular subbase was a time consuming process. First, the pavement was broken with a pavement breaker. Next, the rubblized pavement was hauled to a plant site, crushed and then hauled back to the project site. In 1993, Manatt's Inc., Duit Construction and Wendling Quarries developed a concept to break, crush and recycle the pavement on site utilizing a mobile crushing operation. This concept, known as the "Paradigm", reduced construction costs, reduced haul road maintenance and increased safety because dump trucks were no longer hauling in and out of the construction zone. The mobile crushing operation was first used in 1993 on a section of I-80 in Jasper County. Two years later, an estimated \$800,000 was saved on the 14 mile interstate reconstruction on I-80 in Jasper County.



Figure 7 - "Paradigm" Mobile Crushing Equipment

Aggregates

Aggregates account for approximately 70 percent of the concrete volume. The aggregates ability to withstand the effects of the environment directly impacts the durability of the concrete, especially in pavements. In the early 1900s, it was observed that properly proportioned and cured concrete continued to gain strength over time and it was popularly believed that aggregate was of little importance if water was controlled and proper strength had been attained. Later, it was noted that even properly controlled concrete exhibited deterioration within a few years, especially concrete exposed to severe conditions of moisture and temperature or a chemical environment. Thus, the careful selection of durable materials is required to produce concrete with any degree of durability. In Iowa, the geologists have worked to determine proper ledge control, document service history of sources, and improve and develop test methods to ensure the quality of concrete aggregates.

Prior to the 1920s, locally derived pit run gravel was used extensively in concrete pavements. When approved by the engineer, pit run gravels were tested frequently to ensure the amount passing the one-quarter inch screen did not exceed 60 percent. Later concrete mix designs consisted of a combination of coarse aggregate and fine aggregate, or sand. Iowa sands, in general, are composed of hard durable quartz particles. Shale and coal particles found in some sands caused failures in concrete at the surface and a limit of 1 percent maximum was in effect from 1925 to 1932. From 1933 to 1947, the maximum permissible amount of shale and coal was 1.5 percent. In 1948, the maximum permissible amount of shale and coal was raised to 2.0 percent.

Prior to 1948, sand sources not meeting the grading requirements were required to meet mortar strength equal to that using standard Ottawa sand. Beginning in 1948, sand sources were required to pass a mortar strength test of not less than 150 percent of the strength of a mortar using graded Ottawa sand.

Gravel coarse aggregates were used quite extensively in the early 1900s through the 1930s. Many are buried fairly deep by glacial till and most were carried considerable distances by rivers and streams flowing out from areas covered by glaciers. With the exception of Mississippi River sands north of the Rock River, all gravels contain some unsound particles. Depending on glacial origin and what sedimentary formation the river or stream traverses, most contain some percentage of shale, unsound limestone, soft sandstone, iron impregnated shale, or coal. Iowa gravels commonly contain high percentages of chert particles; however, most appear to be relatively sound. Even with the inclusion of a limited percent of undesirable materials in the gravels, most provided fairly good performance in PCC pavements.

Platte River gravels (Class V aggregate) began use in 1927 in Iowa. Approximately 370 miles were paved between 1927 and 1931. A substantial number of these pavements exhibited a surface map cracking within 10 years. Research in the 1940s noted the use of coarse limestone, at 30 percent, eliminated the map cracking. Since 1946, the Nebraska Department of Roads (NDOR) used the mix designated as 47-B containing 30 percent durable coarse limestone, six bags of cement per cubic yard and air entrainment. All pavements utilizing the 47-B mix have had good performance. It was also found in Iowa that the use of 5 percent limestone screenings also produced concrete with satisfactory performance.

In the early 1900s, limited amounts of limestone were used. The main sources utilized were Alden, Iowa Falls, Buffalo, East Peru, and a few others. During this time, the only laboratory test for durability was the sodium sulphate soundness test, typically used for building stones. This test was sensitive to temperature variations and was not a reliable indicator of aggregate durability. A freeze-thaw test, developed for testing drain tile, was applied to aggregates. While the results indicated some limestone aggregates were lacking in durability, it was assumed that a matrix of mortar would afford protection to the particles of coarse aggregate. This was a false assumption and not readily apparent until 10 to 15 years later, when cracking occurred near the joints and other areas of high

moisture, such as in a cut location.

When mechanical refrigeration made it possible to conduct freeze-thaw tests in the laboratory, samples were placed in pans partly filled with water in cold air and samples were dried before freezing. Results from this method correlated to service history of some aggregates, but correlated poorly with others.

When larger freezing equipment was acquired, it was designed to cool a nonfreezing solution in which pans containing the samples could be placed and cooled quickly. A solution of water and methyl alcohol was used as the cooling medium. When results obtained from freezing in air were compared with results obtained from freezing samples by placing the containers in a solution of water and methyl alcohol, those frozen in the sample pans in the water alcohol solution were more seriously disintegrated compared to those frozen in air. It was noted that some of the alcohol fumes were being condensed in the sample container. After some investigation, it was proved that the small amount of alcohol entering the water was responsible for the difference.

A large number of samples were tested with 25 freeze-thaw cycles with samples surrounded by pure water and duplicate samples tested with 16 freeze-thaw cycles surrounded by 99.5 percent pure water and 0.5 percent methyl alcohol. A shaly limestone disintegrated 30 times greater in the water alcohol solution compared to the pure water. In 1948, the alcohol method of freeze-thaw testing aggregates (Method A) was adopted in the specification and had become a fairly reliable method relating service behavior of concrete pavements. This has led to the elimination of a number of quarries used for concrete work. However, there were still a few aggregates that passed the alcohol freeze-thaw test, but did not exhibit good service history. At the time, other work was being done studying the clay minerals in limestone. Results of this work indicated the type and percentage of clay minerals present has a considerable effect on the durability of the concrete with the limestone.



Figure 8 - Method "A" aggregate freeze-thaw equipment

In 1956 and 1957, the Bethany Falls (Winterset) quarry at Logan and the Argentine quarry at Menlo were approved. Alcohol freeze-thaw tests indicated they were significantly better than the Earlham beds, an aggregate of known poor quality. These sources were subsequently used during construction of I-29 north of Council Bluffs in 1958, I-80 in Pottawattamie County in 1959 and I-80 Cass County in 1959.

Within three to five years, extensive cracking was noted at the joints in these pavements. In 1964, the producer was informed they could no longer supply Argentine stone for interstate pavements. A limited amount of pavement had been placed on the interstate and primary system using the Winterset ledges and the D-cracking had not begun to appear at this time. It was suspected that D-cracking would occur at a slower rate. In 1965, the Winterset stone was limited to a maximum of 1 inch top size to delay D-cracking. D-cracking did occur a few years later with the Winterset stone and, in 1967, it was no longer acceptable for use on the interstate system.



Figure 9 - D-Cracking on U.S. 218 MP 46 - 1970s

In 1967, a study¹ of D-cracking pavements revealed the Argentine and Winterset members of the Pennsylvanian age formation, Otis member of the Wapsipinicon formation and Coralville member of the Cedar Valley formation were showing significant D-cracking within five to 10 years during this time. Other sources, such as the Maynes Creek member of the Hampton formation, had exhibited D-cracking in the late 1930s. The Argentine and Winterset stones were basically calcitic limestone, while the Otis and Coralville stones were calcitic dolomites or dolomitic limestones. Satisfactory service history had been obtained with aggregates containing less than 5 percent or more than 16 percent MgO content. Satisfactory performance was also obtained from a mix of limestone and dolomite as separate distinct rock in a working face.

Eventually, the D-cracking problem led to the development of the durability classification system. In 1971, two classes of aggregates were recognized. Class 2 aggregates would be considered good for use on the interstate pavements. Good aggregates should last for 25 to 30 years in pavement without significant patching required. A durability rating of 80 at 300 cycles tested by ASTM C 666 Method B was considered acceptable. A 90-day cure period was found necessary to achieve critical saturation and ensure that cement hydration was not a factor. Nearly all gravel sources generally performed well, although some sources indicated D-cracking. The D-cracking of gravel sources was affected by the amount and durability of the carbonate fraction. Class 1 aggregates were still utilized in structures and primary paving.

In the 1970s, Wendell Dubberke, Office of Materials geologist, began to study the pore system of limestones with good and poor service history. He noted that aggregates failing the alcohol freeze-thaw test contained various amounts of shale, clay and tripolitic chert above 5 percent. He noted the D-cracking problem was related to pore size. This relationship led to the development of the Iowa Pore Index test², which has

been in use since 1978. The test uses 9000 grams of one-half inch material in an airtight pot filled with water and pressurized to 35 psi to force water into the pore system of the aggregate. At one minute, the primary load is recorded by the milliliters of water entering the large pores. At 15 minutes, the secondary load is recorded as the milliliters of water to fill the small capillary size pores. The secondary load is the pore index number and gives an indication of long-term freeze-thaw durability of the capillary pore system. A lower number indicates better freeze-thaw performance. For Class 3-I, 3 or 2 the pore index should be less than 20, 25 and 30, respectively.



Figure 10 - Iowa Pore Index test equipment

In the early 1980s, the Federal Highway Administration (FHWA) began requiring the use of fly ash. As fly ash usage increased, the Iowa Department of Transportation (DOT) increased the durability requirement of carbonate sources to those with long term service history. Those with large pore systems, or pore diameters greater than ± 10 microns, were classified as Class 3 aggregates. A durability rating of 90 at 300 cycles tested by ASTM C 666 Method B was considered acceptable for Class 3. In November 1982, the durability classification system was broadened to Class 3 aggregates for use in pavements utilizing fly ash, Class 2 for other pavements and Class 1 for structures. In November 1983, Class 1 aggregates were dropped from the classification system and Class 2 was then required for structures. In 1992, due to increasing design life requirements for interstate pavements up to 40 years, Class 3I aggregates were added to the classification system for use in interstate pavements.

In 1983 during I-380 construction, it was noted that one of the sources being utilized was exhibiting deterioration similar to D-cracking on Iowa 8 in Tama and Benton counties placed in 1971. The aggregate source was from the Garrison quarry. This

aggregate has a very good pore system by the Iowa Pore Index test and typically yields durability factors above 90 when tested by ASTM C 666 Method B. Based on the information at the time, it should have produced long term durability in pavement. Unfortunately, on primary pavements, or other pavements that received deicing salts, joint deterioration appeared in 10 to 12 years and patching was required within 20 years. Using X-ray diffraction (XRD), geologists noted a peak shift from pure dolomite correlated very well to service history. This shift from pure dolomite was either due to iron substitution or other impurities in the dolomite crystalline structure³.

Because none of the physical tests, such as alcohol freeze-thaw test or the Iowa Pore Index test, were able to detect all aggregates of poor durability, Wendell Dubberke continued to work on further defining aggregate quality for pavements. Utilizing X-ray fluorescence (XRF), it was noted that strontium (Sr) greater than 0.05 percent relates to poor performance of limestone aggregates. Excessive manganese (Mn) in dolomite aggregates relate to poor performance. Thermo-gravimetric analysis (TGA)⁴ was also used to detect grain size of dolomites as fine to medium grained dolomites perform poorly compared to large grain dolomites. TGA is also used to detect clay in limestone aggregates.

As geologists developed a history of correlation to these new tests, the tests became the basis for acceptance for aggregates used in concrete. Correlation with geologic units with a service history and testing could be used to assign a durability classification. In 2001, the specification for determining aggregate durability classification was based on the pore index testing and salt susceptibility, utilizing XRF, XRD and TGA. Alumina oxide (Al_2O_3) of less than 0.5 percent by weight, tested by XRF, was also used to determine if the alcohol freeze-thaw test was required.

Recycled PCC aggregate has been used on a few paving projects in Iowa. In 1976, the first Iowa DOT research⁵ project utilizing recycled concrete as aggregate was conducted on U.S. 75 in Lyon County. Other than the mix being somewhat harsh, the Lyon County project went fairly well. Based on the success of the Lyon County project, similar recycled research projects were placed in 1977 on I-680 in Pottawattamie County and in 1978 on Iowa 2 in Taylor County. Greene County also recycled concrete pavements as aggregate on several projects in the late 1980s.

Mix design

Prior to 1924, proportioning of concrete was based on volumetric method. R. W. Crum, Iowa Highway Commission's materials and tests engineer at the time, developed the method of batching by weights to account for variation in cement content due to variation in aggregate moistures based on volumetric batching. Duff Abrams, Portland Cement Association (PCA), presented his paper⁶ at a 1927 conference in Amsterdam, and this method became the standard method of batching worldwide.

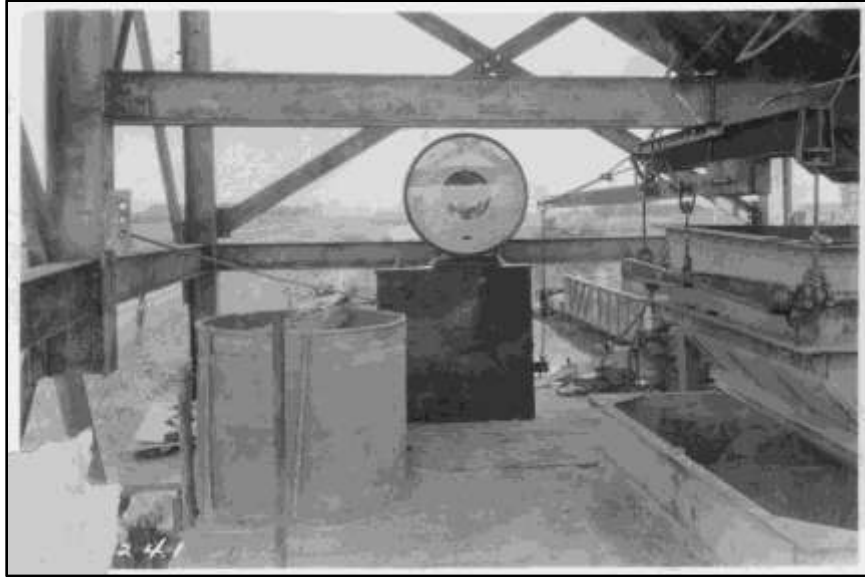


Figure 11 - Weigh scale and aggregate hopper – Woodbury County 1921

The early mixes contained water, cement, sand, and rock. Proportions have remained relatively consistent during the past 100 years. Table 2 in the Appendix contains a list of mixes used on standard concrete pavement. Cement content was specified by the sack (bag) or given in partial barrels (376 pounds or four sacks).

Cement contents varied from six and a half to eight sack mixes (613 to 752 pounds per cubic yard) until 1951, six to seven sack mixes (564 to 658 pounds per cubic yard) from 1952 to present. Much of the service history of aggregates has been based on the mixes used on the primary system. Until the 1990s, the mixes utilized on the county system were typically lower cement content, requiring higher water to cement ratios and, thus, higher permeability. Coarse aggregate service history on the county system was more variable, or even worse, with certain aggregates compared to the primary system.

During the 1980s, fast-track paving was investigated to expedite PCC pavement construction⁷. Class F and Class FF mix designs, utilizing Type III cement at 710 pounds per cubic yard and 822 pounds per cubic yard, respectively, were first used in 1986 on U.S. 71 in Buena Vista county overlay. The Type III cement allowed traffic to be driving on the pavement within eight to 12 hours. Eventually, many of these pavements utilizing high amounts of Type III cement exhibited deterioration problems due to the extremely high curing temperatures. The maturity method of determining opening strength, as is used today, has allowed opening to traffic to occur within 24 to 48 hours without the need for Type III cements.

In 1997, the first contractor quality management concrete (QMC) mix design project was let on Iowa 5 in Warren County. This project involved the contractor designing mix proportions to meet a compressive strength incentive⁸. In 1998 and 1999, several more

projects were let utilizing contractor mix designs with an incentive based on flexural strength, third-point loading (MOR-TPL). Minimal mix improvement was required to achieve the strength incentive. Because mix placement and workability has an impact on durability and there was little correlation of strength to durability, it was decided to try another method to improve mix workability. In 2000, an incentive based on well graded aggregates utilizing the Shilstone gradation method was implemented. Well graded aggregate mix designs provided improved placement characteristics. In 2001, the highly sanded C-5 and C-6 mix designs were no longer allowed on interstate and primary paving projects.

Slump requirements, when mechanical finishing was used, varied from 1½ inches in 1925, to 1 inch in 1930, and then increased to 2 inches in 1933. In 1948, the slump range became one-half inch minimum to 1½ inch maximum. The maximum was raised to 2 inches in 1964, 3 inches in 1984 and reduced to 2½ inches in 1992. Slump requirements were eliminated in 1998 for slipform paving.



Figure 12 - Testing slump and cylinders – Dallas County 1921

Materials

Due to availability of raw materials, Iowa has had a number of Portland cement producing plants. Ownership has changed, but the location of the main suppliers has been at the Lehigh and Holcim plants (formerly Northwestern States) in Mason City, Lafarge plant (formerly Dewey Portland) in Davenport and the Ash Grove plant in Louisville, Neb. Cement was also produced at the Marquette plant in Des Moines and Penn Dixie plant in West Des Moines, but production ceased at both plants in the early 1980s. Various other suppliers from surrounding states have also supplied Portland

cement, but the aforementioned plants supplied the majority of paving work.



Figure 13– Northwestern States cement plant 1908- from the collection of Hank Zaletel.

The main types of cement produced were Type I and Type I/II. Until 1982, the equivalent alkali limits were 0.75 percent and 0.60 percent when Class V gravels were used. Between 1982 and 1995, the equivalent alkali limit was increased to 0.90 percent⁹.

In the early 1990s, several pavements began exhibiting a new type of deterioration that occurred in three to five years that was not related to the coarse aggregate¹⁰. Several studies¹¹ came to varying conclusions as to the cause of the deterioration. To be conservative on all theories, in 1996 Portland cement specifications placed an SO₃ limit of 3.0 percent and an equivalent alkali limit of 0.60 percent¹². Later research¹³ indicated the deterioration was related to inadequate air void system due to excessive vibration. In 2004, the 3.0 percent SO₃ limit was removed and standard ASTM C150 limits applied.

In 1994, test sections utilizing Type IS cement were placed on U.S. 63 in Bremer County¹⁴. The first project utilizing Type II cement with 35 percent replacement with ground granulated blast furnace slag (ggbs) was placed in 1995 on Iowa 100 in Linn County. The first ternary mix, utilizing a Type IS(35) cement and 10 percent Class C fly ash substitution was placed on U.S. 151 in Linn County in 1997. Also in 1994, a test section utilizing Type IP cement was placed on I-29 in Pottawattamie County¹⁵. The first Type IP cement was produced by intergrinding calcined clay at 17 percent. The first ternary mix project, utilizing Type IP and 10 percent Class C fly ash, was placed on I-29 in Pottawattamie County in 1995. In 2005, the Type IP cement was produced by blending with 25 percent Class F fly ash.

Fly ash test sections were first placed in 1978 on a Woodbury County paving project¹⁶.

Primary road fly ash test sections were placed Hamilton County Iowa 175 project in 1980¹⁷. The first project to contain fly ash was a project U.S. 61 in Muscatine County in 1982. Both pavements are performing well to date. Since 1984, 15 percent fly ash substitution by weight has been at the option of the contractor's. Substitution was increased to 20 percent in 1995, reduced to 15 percent in 2000 to accommodate blended cements and increased to 20 percent again in 2004 for all cement types. Fly ash substitution was not allowed from October 15 to March 15, until the maturity method of opening pavement was implemented in 1997.

In 1952, air entrainment of 3 to 5 percent (5 to 7 percent for Class V aggregates) was required for the first time. In 1956, the air content was increased to 4 to 6 percent. In 1960, air entrainment was increased to 6 percent $\pm$ 1 percent. To account for loss of air through newer paving equipment with hydraulic vibrators, air entrainment was increased to 7 percent $\pm$ 1 percent in 1995. In 2001, the air loss behind the paver was determined and added to 6 percent as the target air content in front of the paver. Based on hardened air contents in cores obtained on projects from 2002 to 2007, it was discovered that the average in place air content was greater than 8 percent. A loss of 1.5 percent was assumed for most mixes and pavers. In 2008, the target air content became 8 percent $\pm$ 2 percent.

Water reducers were first used in 1974. Also in 1974, The C-3WR and C-4WR mix designs were added, which included a 5 percent cement reduction versus a standard Class C paving mix. The C-6WR mix design was added in 1979.

Concrete batching

Early batching was done by hand. Dump trucks would haul the rock and sand and dump the materials along the roadside. The workers would use wheelbarrows, also used as a volumetric measure, to batch the aggregate into the skip hoist. Cement bags, spaced along the roadside, were added at approximately two bags of cement per 11 cubic foot batch. The skip hoist would tilt the dry materials into the mixer.

A water pipe with multiple outlets was laid the entire length of the project to provide water. Duplicate pumping equipment was required to ensure against breakdowns.



Figure 14 - Water lines and pumping equipment – Shelby County 1930s

The dry materials and water were mixed in the mixer and then deposited on the grade. This process was slow and labor intensive, but produced many good concrete roads.



Figure 15 – Batching concrete aggregate using wheelbarrows and cement bags

In the early 1920s, aggregate batch plants could load rock and sand into separate bins on trucks or small rail car bins. Trucks or rail were used to haul the sand and rock to the mixer. By the late 1920s, bulk cement became available, which led to cement batching plants that stored and weighed cement. The cement could be loaded onto the trucks,

eliminating the labor intensive use of bagged cement.



Figure 16 - Trucks lined up at aggregate batch plant - Woodbury County 1921



Figure 17 - Truck dumping into skip hoist - Woodbury 1921



Figure 18 - Bulk cement dumping into truck – Howard County 1931



Figure 19 - Aggregate batch plant and rail lines – Wapello County 1926



Figure 20 - Lifting rail box into skip hoist – Wapello County 1926



Figure 21 - Koehring paver mixer – Wapello County 1926

As capacity of dump trucks increased larger batches could be mixed. The limiting factor was the mixer which slowly grew from 11 cubic feet to the 16E (17.6 cubic feet), then to 27E (29.7 cubic feet) and then to the 34E (37.4 cubic feet) mixers. Utilizing twin or triple batch mixers greatly increased production.



Figure 22 - Twin 34E mixers - Story County U.S. 30 1964

Central mix paving began in the 1960s and eventually became predominant method during the building of the Interstate Highway System where high production and concrete consistency was required. Concrete was delivered in dump trucks or agitor trucks. Dry batching of concrete began to disappear in the 1960s. Mixing time has been at one minute since the early 1920s.



Figure 23 - Central batch plant – Cass County I-80 1965



Figure 24 - Agitor truck dumping in front of paver – Dallas County I-80 1966

Concrete placement

Prior to the invention of the slip form paver, all concrete pavements were placed using

side forms. Forms used to support the finishing machine were to be made of steel. After the forms were set and locked, a mechanical tamper was to be used on both sides of the form to force suitable material into intimate contact with the base of the form.



Figure 25 - Mechanical form tamper – Shelby County 1930s

Forms were required to be cleaned and oiled before any concrete was to be deposited against them. Forms were required to be left in place no less than 15 hours after the concrete was placed.

Early pavements were struck off using a strike board cut to crown and proper length to span the full width between forms. The strike board was 2 inches thick with iron bound to the lower edge.



Figure 26 - Striking off concrete by hand – Story County 1922

As machines began to replace manual labor, concrete was struck off with a mechanical finishing machine.

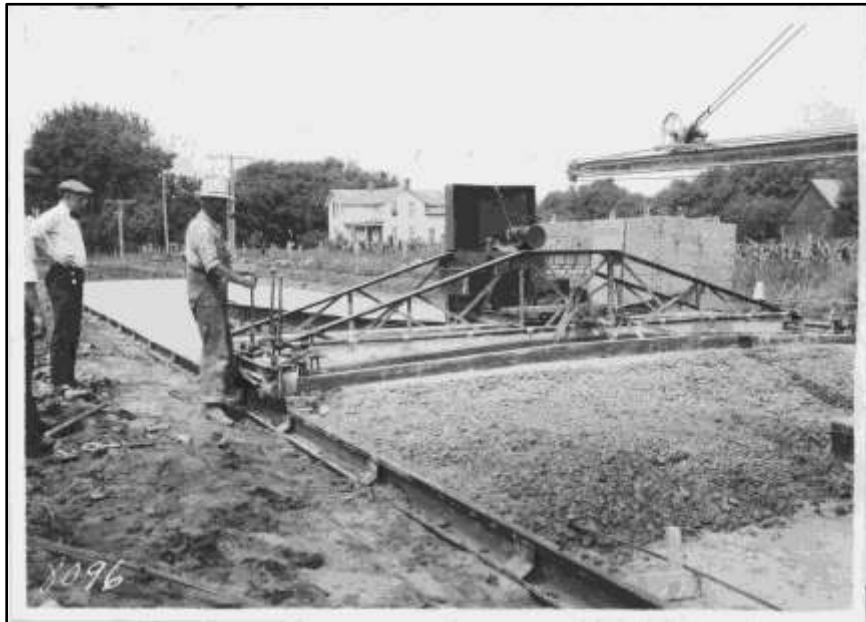


Figure 27 - Lakewood finish machine – Dallas County 1921

Until 1930, after the concrete was leveled off to an elevation above that shown on the plans, the concrete was required to be tamped by hand or mechanical tamper until thoroughly compacted.



Figure 28 - Mechanical tamping and boards – Blackhawk County 1921

The slip form paver

In 1947, James Johnson and Bert Myers, Iowa Highway Commission Office of Materials, conceptualized the slip form paver¹⁸. They developed a sidewalk slip form paver and placed a 3-inch thick, 18-inch wide sidewalk without forms. In 1948, the prototype was improved and a 5-inch thick by 4-foot wide sidewalk was placed. In September 1949, the first slip form paver was used to place a 20-foot wide section, in two 10 foot passes, for one half mile near Primghar in Obrien County. In October of that year, a one-mile section 20 foot wide (two 10-foot passes) was placed in Cerro Gordo County between U.S. 18 and Iowa 106. On these two projects a 3- to 4-inch gap between the lanes was filled with asphalt.

There was little advancement made with the slip form paver the next five years. The Greene County engineer wanted to try the slip form paver and secured permission to rent the pilot model to place a two mile project. In 1954, the slip form paver was leased to Ray Andrews Sr., Andrews Concrete, to pave a road near Churdan in Greene County. This project utilized PCC to fill the 3- to 4-inch gap immediately following construction of the second lane.



Figure 29 - Johnson slip form paver Greene County 1954



Figure 30 - Johnson slip form paver closeup - 1954

In 1955 Quad City construction developed the first self-propelled, full-width slip form paver. This paver did not have a hopper and the concrete was deposited directly on the grade. Quad City Construction placed approximately 28 miles of slipform paving in

1955. A few years later, several manufacturers began marketing slip form pavers.



Figure 31 - Quad City slip form paver – Palo Alto County 1957

The slip form paver concept was originally developed as a method of improving concrete pavement placement on secondary roads, where narrow widths do not allow trucks to operate on the shoulder to pick up forms and haul them ahead.

In the mid-to-late 1960s, another significant improvement to allow full-width concrete placement on secondary roads was the Iowa Special. A conveyor was attached to the front of the subgrade trimmer to allow the contractor to bring concrete delivery vehicles down the grade in front of the trimmer to place material on the conveyor while trimming the subgrade or subbase immediately before the material was deposited on the grade.



Figure 32 - Iowa Special trimmer/placer - Dallas County 2009

The 1964 specifications first included the use of the slipform concrete pavement. Although, the first section of interstate pavement utilizing slip form was placed in 1964 in Iowa County, it was not until the late 1970s and early 1980s that slipform paving became the predominant method of concrete pavement placement it is today. Typical paving train consists of the belt placer/spreader and the slip form paver.

The paving machine sensors, control horizontal alignment and vertical elevation, reference their position by sliding along the string line that has been surveyed to the final profile of the roadway surface. The string line has a major impact on the smoothness of the pavement.



Figure 33 - Dump truck and belt placer/spreader - Polk County 2006



Figure 34 – Gomaco slip form paver - Henry County 2005



Figure 35 - Gunntert-Zimmerman slip form paver - Osceola County 2007

Vibration

In 1937, internal vibration was required within 18 inches of all expansion, contraction, and construction joints, including the center parting strip. All vibrators were to be operated at not less than 3500 vibrations per minute.



Figure 36 - Vibration near expansion joint - Bremer County 1936

In the 1948 specification, vibration on the mechanical finishing machine replaced the requirement for tamping. Concrete being struck off shall be consolidated by means of a vibrating screed or pan operating on the surface of the concrete or by means of a vibrating tube or assembly of tubes. Vibration rate was required to be not less than 3500 vibrations per minute.



Figure 37 - Vibrators and tubes – Fayette County 1936

In 1952, specifications required consolidation of the concrete with vibrating tampers, tubes or arms for concrete placed by machine methods. The vibration rate was to be not less than 3500 vibrations per minute. In 1977, the vibration rate was increased to a minimum of 7000 vibrations per minute and a requirement to apply supplementary vibration at the dowel baskets was included. Vibrators on early paving equipment required higher vibrations to impart consolidation in the concrete. As paving equipment became larger and hydraulic vibrators became more efficient, a high degree of consolidation was imparted into the concrete at the higher vibration rates.

In 1991, a section of U.S. 20 in Hamilton and Webster counties placed in 1987, began to show visible deterioration along vibrator trails and at the joints. This type of deterioration began to appear on several other paving projects placed between 1986 and 1994. Several research projects^{9,12,19} noted the loss of air in the vibrator trails and at the joints increasing the exposure to freeze-thaw damage.



Figure 38 - Vibrator trails in pavement - Dallas County

In 1995, supplemental vibration at the dowel baskets was eliminated and the vibration rate was changed to a range of 5000 to 8000 vibrations per minute. A 1995 research project²⁰ validated this vibration range. In 1997, the requirement of vibration monitoring²¹ equipment was included on paving projects greater than 50,000 square yards. As contractors gained experience with well graded paving mixtures, they indicated the mix workability would allow lower vibration. In 2001, the vibration rate was changed to a range of 4000 to 8000 vibrations per minute.



Figure 39 - Vibration monitoring equipment

Finishing and texture

Longitudinal finishing was accomplished by a 12-inch by 3-inch by 12-foot wood float. Immediately after longitudinal floating, the surface was struck off by heavy 10-foot straightedges set parallel to the centerline.



Figure 40 - Longitudinal finishing – Polk County 1926

From the 1920s to 1952, surface texture was produced by belting. An 8- to 10-inch belt

was rubbed across the surface to produce a gritty texture.



Figure 41 - Belting surface – Polk County 1926

From 1952 to 1959, final finish after belting was accomplished by two layers of wet burlap or carpet drag. From 1960 to 1975, the required texture was to produce a gritty texture by burlap, carpet drag or by broom finish. A test section of transverse tined pavement was placed on U.S. 63 in Tama County in 1969.

In 1976, *Guidelines for Skid-Resistant Pavement Design* was published by American Association of State Highway Transportation Officials (AASHTO). In order to ensure safe wet friction, Iowa implemented turf, coarse carpet or burlap micro texture and a three-quarter inch spaced transverse tining macro texture in 1976. In 1988 to 1989, the spacing was increased to 1½ inch centers. The 1½ inch wide tining proved to be very noisy and was changed back to three-quarter inch spacing in 1990. In 1992, burlap was deleted as a micro texture option. In 1993, a research project²² was implemented to determine noise, friction, and ride values on a variety of texture test sections on Iowa 163 in Polk County.



Figure 42 - Transverse tining - 1998

In 1999, in order to improve noise characteristics, the contractor was given the option of either a uniformly spaced three-quarter inch longitudinal tining or a randomly spaced, three-eighths inch to 1 $\frac{5}{8}$ inch, transverse tining. The majority of the contractors opted to utilize longitudinal tining which also expedited placement of curing compound after final finishing. In 2005, burlap was again added as a micro texture option to improve the surface on zero blanking band smoothness projects.

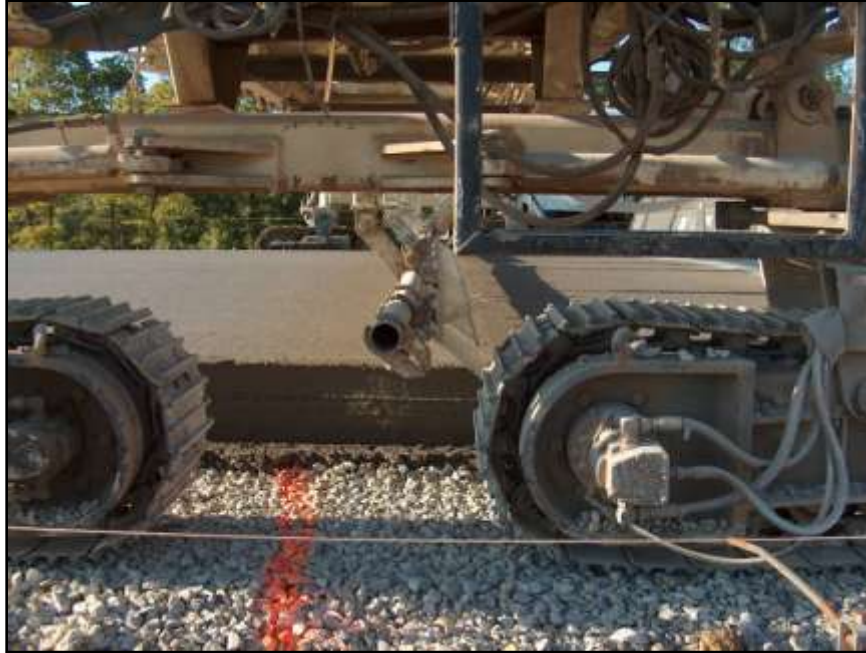


Figure 43 - Longitudinal tining - 2002

Curing

Prior to 1930, curing was accomplished by wet burlap curing for 24 hours. After 24 hours, the pavement was covered with a minimum of 2 inches of sand or wet earth, or 6 inches of straw. After October 15, calcium chloride curing, at a rate of 2 pounds per bag of cement, was required with 2 inches of wet burlap for 24 hours. Calcium chloride curing was eliminated in the 1964 specifications.

Other methods of curing, included curing with impervious paper (two to three layers of kraft paper bonded with asphalt and fiber) for seven days, 2 inches of wet burlap for 72 hours, or impervious coatings.

Beginning in 1930, the sand or wet earth or straw was required to be left in place for a period of six days and opening to traffic was allowed in seven days.

The 1925 specifications allowed curing by ponding with a minimum depth of 2 inches of water was allowed in lieu of earth cure. In 1948, curing by ponding was added back to the specifications. Ponding was achieved by earth dikes to cover the pavement with a minimum of one-half inch water depth for 48 hours after the burlap was removed.



Figure 44 - Burlap and water curing – Woodbury County 1921



Figure 45 - Earth curing - Woodbury County 1921



Figure 46 - Curing by ponding - Mitchell County 1930s



Figure 47 – Sisalkraft paper curing – Washington County 1930



Figure 48 – Curecrete bituminous curing - Pottwattamie County 1920s

As the slip form paver gained more widespread acceptance, white pigmented curing compound applied after final finish was the method most generally used. This was because water trucks could not be used along the edge of the pavement. Also, white pigmented curing did not break down the fresh pavement edge as water curing would.



Figure 49 - White pigmented curing - Tama County 2005

Opening time and strength

Prior to 1930, opening to traffic was not allowed until 21 days between June 1 through September 1, and additional time was determined by the engineer during other periods. Between 1930 and 1937, opening to traffic was not allowed until seven days.

Since 1937, the time for opening has been based on a flexural strength of 500 psi, modulus of rupture center-point loading (MOR-CPL). Contractor forces were allowed on the pavement after the minimum age period of seven days for standard Class C concrete. In 1972, the minimum age period became five days for pavements 9 inches or thicker.



Figure 50 – Worker casting flexural strength specimens

In 1997, the maturity method of opening²³ was allowed as an option by the contractor. The contractor was allowed on the pavement after the maturity of the concrete achieved the estimated strength. The maturity concept has allowed the contractor to expedite other work, such as shouldering. During the warm summer conditions, concrete maturity may be reached in 24 to 48 hours.

Jointing and sawing

Prior to 1920, transverse expansion joints were placed every 12 to 36 feet. Between,

1920 and 1925, transverse or longitudinal joints were not placed. Between 1925 and 1930, the longitudinal joint was steel or mastic, but no transverse joints were placed. In 1930, premolded bituminous expansion joints were placed above the dowel bars with expansion tubes, typically at 80 to 100 feet intervals, and finished by hand.



Figure 51 – Moscow Road Muscatine County 1914 - formed transverse joints at 25 foot intervals



Figure 52 - Old U.S. 20 Woodbury County 1921 - no jointing

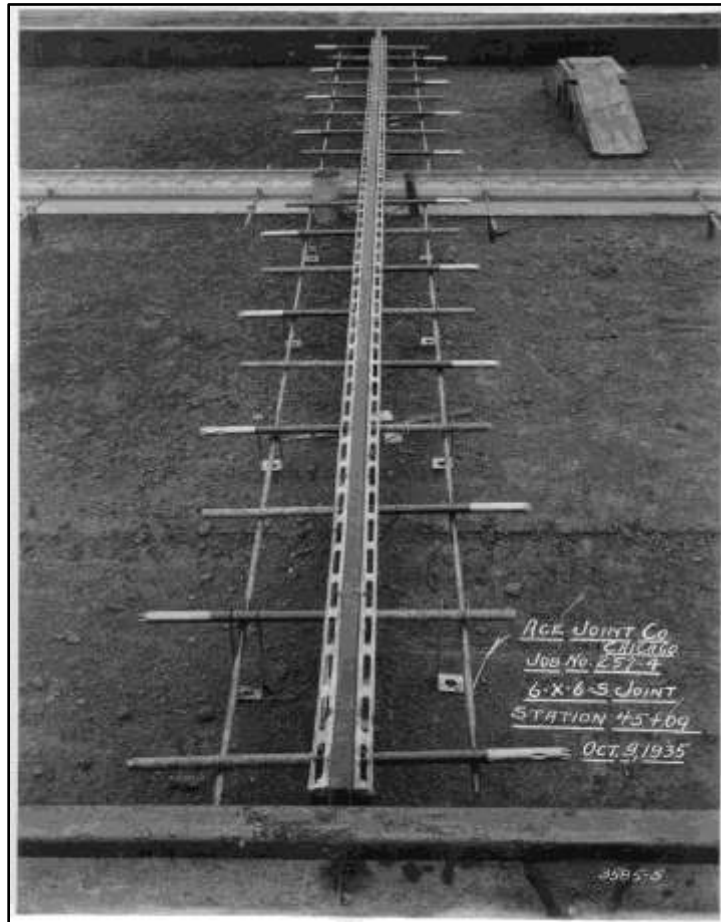


Figure 53 - Expansion joint 1935



Figure 54 - Removing bituminous strip from expansion joint – Montgomery County 1930



Figure 55 - Finishing expansion joint – Montgomery County 1930

In 1933, longitudinal joints were constructed with a metal parting strip with a plane of weakness at 2½ inch from the surface or a premolded bituminous strip installed with continuous operation.

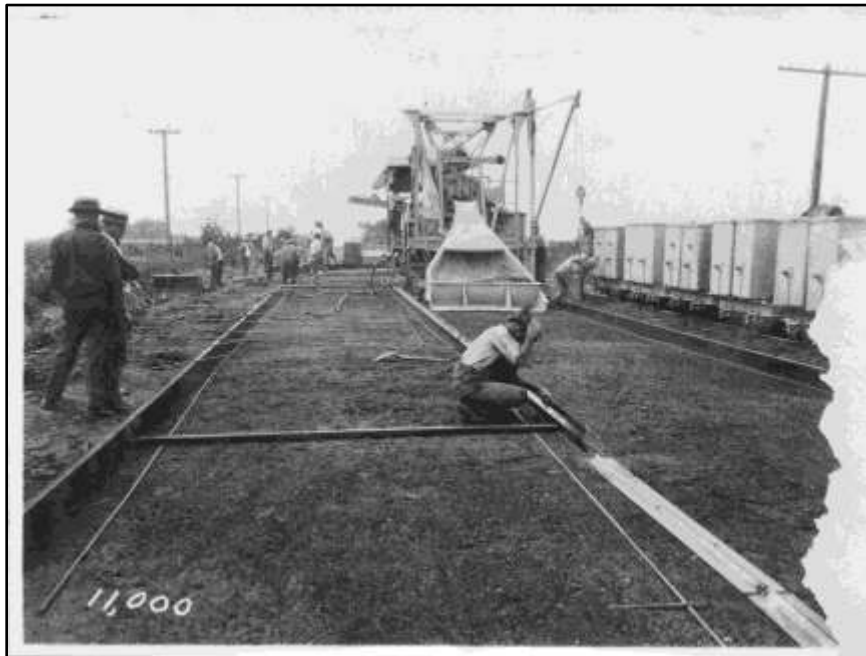


Figure 56 - Placing metal parting strip – Polk County 1926

In the early 1950s, the metal parting strip was inserted continuously. During this same time period, air entrainment began to be required. The combination of stickiness with air

entrainment and the action of the longitudinal finishing, made it difficult to hold the parting strips vertical. The parting strip would deviate from the intended location as much as 3 inches.



Figure 57 - Continuously fed parting strip



Figure 58 – Longitudinal joint with continuous placed parting strip – U.S. 30 Greene County

In 1956, sawing was required for transverse joints and allowed as a contractor option for longitudinal joints. Transverse sawed joints were to be sealed with hot-pour sealant, while sawed longitudinal joints were not required to be sealed until 1960.

Silicone sealants were tried on several interstate paving projects in the mid 1980s²⁴. In 1990, Jim Grove, Office of Materials, and Mark Bortle, Office of Construction, conducted an investigation of joint seals statewide. The investigation revealed the joints with the less expensive hot-pour sealant were performing better than those with the silicone sealants. Poor performance of the silicone sealant was attributed to construction practices, spalling of sawed joints and poor adhesion to limestone aggregates. Since the early 1990s, hot-pour sealant has been used on all interstate and primary pavements.



Figure 59 - Sawing longitudinal joint – Dallas County 1966

In 1990, the early entry saw was used on several nonprimary pavements in Story City, Cedar Rapids, Boone County, Airport Road in Nevada, and Dubuque. Experimental sections were also sawed on Iowa 13 in Coggon, Iowa 17 north of U.S. 30 and I-35 at Milepost 141. In 1992, test sections of transverse joints were sawed utilizing the early entry saw on Iowa 163 in Polk County. On these projects, Bob Steffes, Office of Materials, noted that within 72 hours every second to fifth joints had cracked. Between 72 to approximately 200 hours, no additional joints cracked until construction traffic was placed on the pavement. Early entry sawing has become common practice for sawing of transverse joints.

Early entry sawing was utilized on the longitudinal joint on I-80 in Jasper County in 1993 and on Story County Road E-63 in 1994. Both pavements developed random longitudinal cracking. Based on the random cracking, an investigation²⁵ determined that the early entry saw was not developing a sufficient weakened plane on the longitudinal joint and that a saw depth of one-third the pavement thickness ($T/3$) was required to prevent random cracking.



Figure 60 - Early entry sawing transverse joint

According to Jim Grove, backer rod was first used in 1981 on Dayton Road in Story County. Although many pavements were performing well, deterioration was noted at the centerline joint on some pavements due to freeze-thaw damage around the backer rod. In 2005, the standard for longitudinal joints was changed from a three-eighths inch saw cut sealed with backer rod to a five-thirty-seconds inch unsealed saw cut.

The Wisconsin DOT does not seal any joints on drainable bases and have noted good performance. Test sections of unsealed transverse joints have been placed on U.S. 151 Linn County in 2003 and Iowa 60 Plymouth County in 2006 to investigate the performance in Iowa.

In 2001, Bob Steffes, Office of Materials, developed a concept to form the longitudinal joint in the plastic concrete²⁶. A knife mounted on the slip form paver pan was first used on the U.S. 34 Mount Pleasant bypass. The knife was one-eighths inch wide and 3 inches deep produced a plane of weakness in the plastic concrete. As the concrete matures and shrinks, a hairline crack developed along the plane of weakness. The crack remains very tight and eliminating the need for sawing and sealing.

This process was used on a number of projects from 2001 into 2005 with mixed success. Within a couple years, random cracks began to develop at various locations along the longitudinal joint. It was noted that wet loads combined with excess finishing, including the oscillating screed, possibly worked the plastic concrete to a point that the weakened plane no longer existed. Due to problems with random cracking, the joint forming knife has not been used since 2005, although other states have continued use of the knife.



Figure 61 - Longitudinal joint forming knife on paver pan



Figure 62 - Hairline crack on knifed joint

Pavement smoothness

Prior to 1933, smoothness was checked at the center and quarter points by a 10-foot straightedge. The surface of the pavement was checked by successive positions of the straightedge lapped by one-half the length of the straightedge. Any depressions or high spots greater than one-quarter inch were to be corrected with a carborundum brick or other methods that achieves equivalent results. Beginning in 1933 until 1976, depressions or high spots greater than one-eighth inch were to be corrected with a carborundum brick. In 1977, depressions or high spots greater than one-eighth inch were to be corrected by diamond grinding.



Figure 63 - Surface correction with carborundum brick – Keokuk County 1932



Figure 64 – Surface correction with diamond grinding equipment

By special provision from 1960 to 1963, smoothness testing was performed using the Bureau of Public Roads (BPR) roughometer. The maximum permissible road roughness index shall be 80 percentile of values measured on similar pavements under the supervision of the Commission and counties. Any section with a length of 1000 feet or more and a road roughness index greater than 150 percent of the maximum (any length greater than 200 percent of the maximum) may be removed at the contractor's expense.



Figure 65 - Bureau of Public Roads (BPR) roughometer

In the early 1970's, it was noted that a one-eighth inch in 10 foot criteria for smoothness was no longer adequate in determining the ride of new pavements. With the need for driver safety and comfort at higher speeds, a testing machine capable of detecting with longer profile undulations was required. A 1974 research report²⁷ recommended the 25-foot California profilograph to determine pavement smoothness variations and also develop a specification to help obtain safe, smooth riding pavement for the public.

The Iowa DOT began performing smoothness testing on projects with the 25-foot California profilograph and the BPR roughometer. Advisory smoothness test results were provided early to the contractor so they could take corrective action when indicated.

In 1982, a supplemental specification required interstate and primary mainline pavements to be checked for smoothness by the 25-foot California profilograph. The testing was performed by the engineer at the quarter point utilizing a two-tenths inch blanking band. One-tenth mile segments achieved 100 percent payment for zero to 15 inches per mile, with only disincentives for higher profile index. One-half inch bumps were to be corrected by grinding to a minimum of 36 inches per mile. Transverse texture was required to be regrooved after correction.



Figure 66 - 25 foot California type profilograph

In 1985, profilograph testing was performed by a certified technician of the contractor. Also, any segments of interstate pavements exceeding 15 inches per mile shall be corrected. A 2 percent contract unit price incentive was also added for interstate segments, placed on subbase, constructed at 2 inches per mile without correction and primary segments, placed on natural subgrade, constructed at 4 inches per mile without

correction.

In 1990, any segments of interstate pavements exceeding 12 inches per mile or primary pavements exceeding 33 inches per mile shall be corrected. Smoothness incentive was changed to a 4 percent contract unit price for Interstate segments placed at 2.0 inches per mile without correction. The smoothness incentive for primary pavements remained at 2 percent contract unit price, but the incentive index changed 3 inches per mile without correction for primary segments placed on base or subbase, and 4 inches per mile without correction for primary segments placed on natural subgrade.

In 1994, the contract unit price was paid for a profile index of 3.1 to 7 inches per mile. Smoothness incentive was achieved at 3 inches per mile or less, with a dollar amount per segment as shown in the table below. Additional incentive was applied if all segments in a section qualified for 100 percent payment, with no grinding, and an additional incentive was applied if all segments in a project qualified for 100 percent payment, with no grinding (see Table 7 in Appendix).

In the late 1990s, the Iowa DOT investigated public complaints about the ride quality on a section of I-80 in Jasper County built in 1994 that felt like it had ripples. The investigation revealed the pavement met the current smoothness criteria, in fact the contractor had received smoothness incentive, yet the ride felt choppy. Based on investigation of this project and others experiencing this choppiness, it was found that the two-tenths-inch blanking band covered a small sinusoidal pattern in the profile trace.

In 2004 and 2005, pilot projects were placed utilizing a zero blanking band smoothness specification to reduce the potential for “choppy” ride. In October 2008, the smoothness specification was changed to require zero blanking band on interstate and primary highways. Incentives are applied at 26 inches per mile or lower (see Table 7 in Appendix). Any segment greater than 45.1 inches per mile is required to be corrected.

Pavement thickness

Thickness specifications were included for the first time in the 1964 specification book. The agency was responsible for coring every 2500 square yards. Payment was adjusted by the number of square yards of pavement in each band determined by the average depth deficient from the design thickness. Areas of pavement deficient by more than 1 inch were subject to removal or 10 percent contract unit price.

In 1984, pavement cores were obtained by the contractor every 2000 square yards at locations determined by the engineer. In 1991, a new pay band was implemented with incentives at 102 percent for cores less than design thickness by 0.15 to 0.25 inches up to a 105 percent incentive, if all cores were greater than design thickness (see Table 8 in Appendix).

In 1994 a new quality index was implemented to utilize a statistically based evaluation

of thickness. The quality index was determined by the average core thickness of the lot minus the design thickness divided by the standard deviation. The 100 percent contract unit price was achieved at a quality index of 0.41 to 0.85 up to a 103 percent incentive applied when the quality index was 1.25 or greater (see Table 8 in Appendix).

Contractor concerns of over thick cores affecting standard deviation caused a further change in determining pavement thickness index in 1998. In 1998, the pavement thickness index was determined by the average core thickness for the project minus the standard deviation minus the design thickness. The 100 percent contract unit price is achieved at a thickness index range of (-2.55 to -3.81) up to a 103 percent incentive with a thickness index of zero or greater (see Table 8 in Appendix).

Pavement design

The concrete pavement design history for primary pavements may be found in Table 2 and for interstate pavements in Table 3 of the Appendix. The standard two-lane rural highway designs may be found in the supplemental appendix. The designs are numbered as follows.

- 1 to 67 - two-lane highway designs
- M-1 to M-42 - four-lane highway designs
- W-1 to W-47 - widening designs
- R-1 to R-15 - resurfacing designs.

During the last 100 years, many changes have occurred in concrete pavement designs. In the early 1910s, the pavement was placed with uniform depth. From 1926 until 1957, the thickened edge design was utilized. Typically these designs had alternating transverse steel across the longitudinal joint. Pavement widths started out at 18 feet until the mid-1930s, 20 feet until around 1948 and 22 feet until around 1959. Due to the narrow pavement width placed earlier, numerous curb removal and widening projects were constructed during the 1950s to safely accommodate changes in the amount and types of traffic. In 1960, the pavement width increased to 24 feet and the thickness increased to a uniform depth of 10 inches. Around 1990, the pavement width was increased to 26 feet on four-lane pavements.

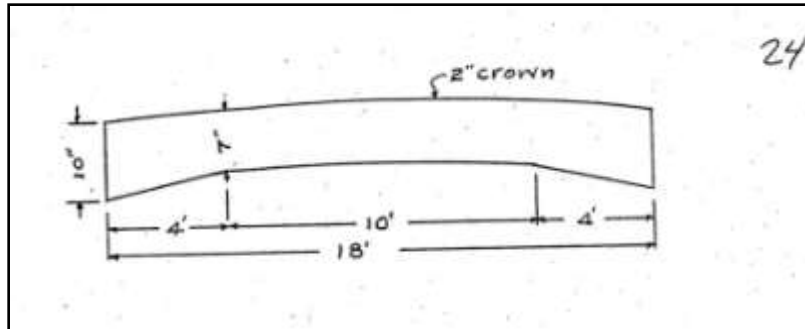


Figure 67 - Thickened edge Design No. 24 10-7-10 - Iowa 141 Dallas and Guthrie counties

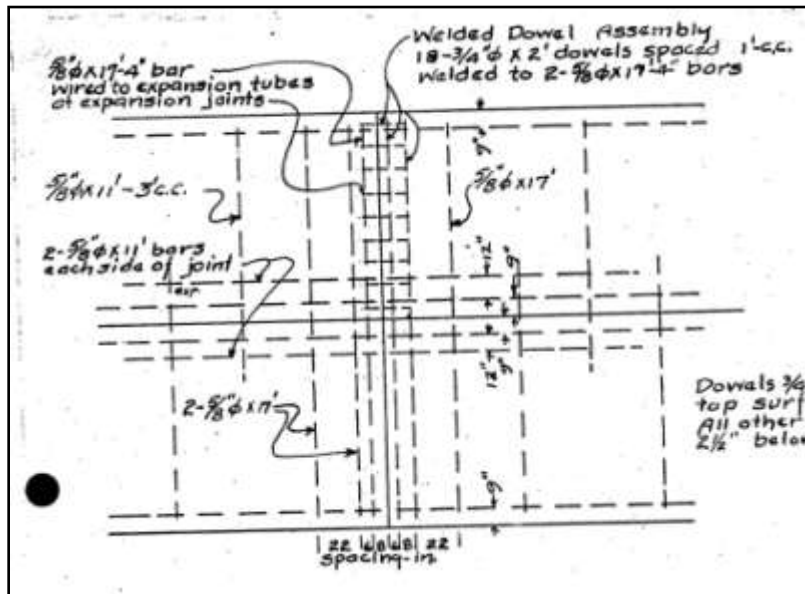


Figure 68 - Reinforcement design Iowa 141 Dallas and Guthrie counties



Figure 69 - Iowa 141 Dallas and Guthrie counties paving - 1950



Figure 70 - Curb removal and widening – U.S. 69 Polk and Story counties 1948

From 1958 to 1969, Iowa plain-jointed pavement designs relied on aggregate interlock and load transfer devices were not specified. In 1969, design standards required load transfer devices when the design year average daily truck traffic (ADTT) exceeded 500 trucks per day. A 4-inch subbase was required if the design year truck traffic was 1000 trucks per day. In 1976, Clare Schroeder investigated²⁸ the magnitude of faulting that was occurring on pavements built 1960 to 1974. Schroeder recommended load transfer be added on the following conditions.

- 10-inch pavement with design ADTT of 300
- An 8.5-inch to 9.5-inch pavement with design ADTT of 250
- Specify subbase when design ADTT exceeds 1000.

In the early 1980s until 1994, subbase was specified when the design ADTT exceeded 700. 1995 and later, subbase was specified when the design ADTT exceeded 300 and dowels were included on pavements 8 inches or thicker. The subbase was typically asphalt treated base (ATB) or cement treated base (CTB), also known as Class A subbase. Portland cement base (PCB) and econocrete base (ECB) were also used as stabilized bases. The last pavements to utilize Class A subbase was in 1988. In 1989 and later, pavements utilized granular subbase (GSB).

In the 1970s, engineers began to recognize that water trapped under the slab was contributing to pumping at the joints and edges. Increased truck loading caused a loss of material support under the slab resulting in faulting. In 1978, a research project was conducted to place longitudinal subdrains on I-80 in Poweshiek County between the Iowa 146 and Brooklyn interchanges. The subdrains were effective in removing water and became standard on new pavement designs in the late 1980s.

Contraction joints were typically placed perpendicular to the centerline until around 1977. The first pavements placed with skewed joints at 15 foot spacing in Pottawattamie County (west of Treynor just south of Iowa 92) and in Harrison County (west and north of Woodbine) in 1964. The first primary project in Iowa utilizing skewed joints without load transfer was on U.S. 52 in Clayton and Dubuque counties in 1975. In 1978, skewed joints were used on projects without load transfer. In 1980, all contraction joints, with or without load transfer, were placed at a 6 to 1 skew. The skewed joint was used to reduce load transfer stress because only one truck wheel crosses the joint at a time. In 2005, the Iowa DOT changed to perpendicular joints and straight dowel baskets, to allow industry to manufacture regionally standard baskets, as Iowa was one of the last states using skewed joints, which requires skewed baskets to be manufactured.

Interstate pavement design

The first sections of interstate placed between 1958 and 1966 were long jointed mesh reinforced designs. Joints were placed at 76.5 foot intervals and allowed to crack in between. A 10-inch thick pavement with 4 inches of granular subbase was the typical design. Placement was typically a two-lift system, with the bottom layer placed first, the mesh reinforcement laid down and the top layer of concrete placed.



Figure 71 - Mesh reinforcement - Dallas County I-80 1966

The first section of continuously reinforced concrete (CRC) pavement was placed on U.S. 30 in Marshall County in 1963 from State Center to Iowa 330. This eight-inch CRC pavement placed on a 4-inch GSB performed quite well with little maintenance. In 1966, the first sections of CRC pavement were placed on the interstate. During the first few years of CRC pavements, the steel was carefully placed on chairs. Later, machinery was developed to place the steel, but led to problems the steel not consistently being located at mid-depth (neutral axis). The interstate CRC designs were 8 inches thick on a 4-inch GSB until 1968 and on 4 inches of CTB or ATB until 1976. Unfortunately, the thinner pavement thickness coupled with the poor steel location and increased truck traffic caused these CRC pavements began to exhibit fatigue failure earlier than expected.



Figure 72 - Continuously reinforced concrete (CRC) steel placement on chairs



Figure 73 - CRC steel fed through machine - Franklin County I-35 1976

In the early to mid-1980s, the standard interstate design for new construction was a 10-inch plain jointed pavement on 4 inches of cement treated base (CTB) or econocrete

base (ECB).

The current full-depth design is a 10- to 12-inch plain jointed pavement on granular subbase that varies in thickness from 9 inches outside edge to 10.3 inches at the centerline to 6 inches on the outside edge. Since 1988, the pavement width was increased to 26 foot with a 14-foot wide driving lane striped at 12 foot, to reduce the edge stress by moving the truck wheel loadings away from the pavement edge.

Concrete overlays

Iowa has a long history utilizing concrete for pavement overlays. The first concrete resurfacing of a brick pavement was in 1932 on U.S. 52 in Dubuque County. The first concrete resurfacing of a PCC pavement was in 1933 on U.S. 18 in Mason City (Cerro Gordo County) and on U.S. 20 in Sioux City (Woodbury County). Several other early bonded concrete resurfacing projects were placed in the 1930s through the 1950s. One example of an early bonded concrete resurfacing project was on U.S. 30 in Benton County on placed in 1949.

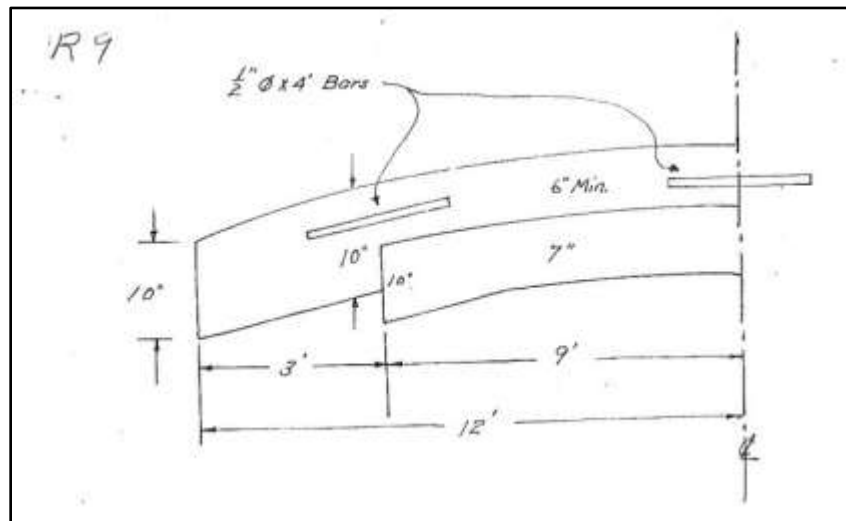


Figure 74 - Concrete resurfacing Design No. R-9 - Benton County U.S. 30 1949



Figure 75 - PCC widening and resurfacing U.S. 30 Benton County 1949

Iowa categorizes PCC overlays into three types:

1. Bonded overlay – PCC bonded to existing PCC pavement.
2. Unbonded overlay – PCC on a composite pavement, using existing hot mix asphalt (HMA) interlayer or new 1 inch HMA layer.
3. Whitetopping – PCC on full depth HMA pavement.

PCC overlays, or resurfacing as it was referred to from 1932 to 1951, was not utilized again until the early 1970s. In 1973, an extensive research project²⁹ in Greene County included bonded and unbonded concrete overlay sections. As oil prices increased in the early 1970s, PCC overlays became more attractive.

Thin-bonded overlay demonstration projects³⁰ were placed on University Avenue in Waterloo in 1976 and on U.S. 20 in Sioux City in 1978. The first overlay of an asphalt pavement project was in 1960 on Woodbury County Road D-38. This project utilized a gravel interlayer. In 1971, the first whitetopping of an existing asphalt pavement was placed on Woodbury County Road L-36 and on the Storm Lake airport. The counties in Iowa have made good use of concrete as an overlay material as many concrete overlays were placed on the county system.

Based on the variety of designs placed on the county system and through investigation of numerous research projects, much has been learned about placement and design of concrete overlays. Experience has shown that bonded overlays are best placed on a pavement in fairly good condition. Do not place a bonded overlay on a pavement built with aggregates that exhibit D-cracking. Also, it is best to not place bonded overlays during cold weather with warm afternoons as in the fall or early spring. The base pavement is contracted in the morning and begins to expand as the temperature

increases while the overlay concrete is hydrating and contracting which can cause the overlay to become de-bond.

Another issue on bonded overlays was trying to replicate the longitudinal joint over the old existing joint. Early entry sawing depth of 1 inch or conventional sawing depth of $T/3$ can cause the sawed joint over the existing joint to become mismatched, eventually causing spalling to occur between the sawed joint and the reflected joint. Allowing the joint to crack on its own has also produced a wandering crack that eventually spalls. The current practice is to saw the longitudinal joint to a depth of at least half of the overlay thickness.

On unbounded overlays, the existing HMA or a new 1 inch HMA interlayer should be used. Asphalt sand seals, used in the past, did not effectively prevent the old badly faulted slab from keying the overlay pavement. Current research is looking at the use of a geotextile fabric as a bond breaker.

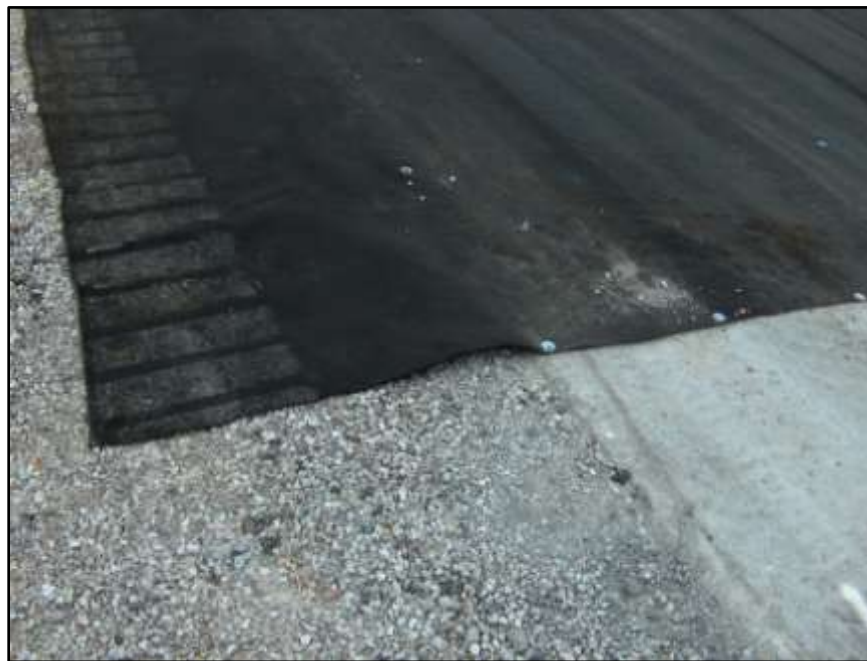


Figure 76 – Geotextile fabric interlayer – Powshiek County 2009

Summary

Over the past 100 years, Iowa has had a rich tradition of innovations in concrete paving. Many of these innovations went on to become industry standards. There have been successes and failures. Industry has built on the successes and learned much from past failures, which has spurred innovation, to achieve a cost effective, long-term, durable solution for highway system that well serves the citizens of Iowa.

The Iowa Concrete Paving Association (ICPA), formed in 1963, and the Iowa

Department of Transportation (DOT) have a strong working relationship that has helped to improve quality and promote innovation. In 2000, the PCC Center was formed at Iowa State University to act upon current concrete pavement research needs. The PCC Center became the National Concrete Pavement Technology (CP Tech) Center and now has the ability to bring together researchers across the country. The partnership of the ICPA, Iowa DOT and CP Tech Center will help to keep Iowa a leader in concrete pavements into the next century.

This partnership has yielded new innovations and improvements in concrete pavement technology. Current research in areas such as string less paving, determining pavement smoothness during construction and nondestructive pavement thickness are currently being investigated. These new technologies and others will certainly affect the way concrete pavements are built in the future.



Figure 77 – String less paving – Poweshiek County 2009



Figure 78 – Noncontact smoothness profile equipment (GOMACO)



Figure 79 – Noncontact smoothness profile equipment (Ames Engineering)



Figure 80 – Metal target before placement to test pavement thickness



Figure 81 – Nondestructive pavement thickness equipment (MIT-SCAN-T2)

Acknowledgements and credits

The author would like to thank the DOT for use of many of the historic paving pictures. Pictures are subject to the following: Copyright © Iowa Department of Transportation. All rights reserved. The author would also like to thank Hank Zaletel, Iowa DOT library, for providing certain background information, Jim Grove, Federal Highway Administration and Gordon Smith, Iowa Concrete Paving Association, for their review of the document.

List of Iowa Concrete Pavements Built 1922 and Earlier

CONCRETE PAVEMENTS IN IOWA BUILT 1922 AND EARLIER

(Built Prior to Designation of State Primary Road System)

County	Length : Miles	Primary : Road No.	Year : Built	Location
Benton	: Approx. 0.5 :	101	: 1912-13 :	North from North city limits of Vinton
Cass	: Approx. 0.5 :	6	: 1915(?) :	East from E. city limits of Atlantic (resurf. with concrete about 1930)
Cerro Gordo	: 1.00 :	18	: 1913(?) :	Begins 1 mi. W. of W. city limits of Mason City. (resurf. with concrete in 1934)
Cerro Gordo	: 1.00 :	18	: 1915 :	W. from W. city limits of Mason City
Cerro Gordo	: 4.07 :	18	: 1918 :	E. from E. city limits of Clear Lake
Des Moines	: 1.00 :	80	: 1913 :	Along S. side of city of W. Burlington
Linn	: 1.00 :	30	: 1918 :	Midway between Cedar Rapids and Mt. Vernon known as the "Seedling Mile".
Louisa	: 1.60 :	2	: 1914 :	In town of Fredonia.
Wahaska	: Approx. 0.5 :	Co. Rd.	: 12-13-14 :	From Eddyville N.E. to Cemetery
Muscatine	: Approx. 0.5 :	Co. Rd.	: 1914 :	W. from town of Moscow.
Polk	: Approx. 0.5 :	Co. Rd.	: 1918 :	W. from W. city limits of Des Moines on University Avenue.

(Built Subsequent to Designation of State Primary Road System)

Benton	: 8.88 :	101-218 :	: 5.17 mi. N.E. and S. of Vinton
	: 30-21 :	: 1921 :	: 3.71 mi. N.E. and S. of Belle Plaine
Black Hawk	: 17.17 :	20	: 1922-23 : 7.60 mi. E. from city limits of Waterloo. Built 1922. Remainder built 1923.
Buchanan	: 14.13 :	20	: 1922 : From Jessup E. thru Independence to Winterset. Wintthrop.
Cerro Gordo	: 5.14 :	18	: 1920 : Clear Lake city limits W. to Co. line.
Cerro Gordo	: 7.43 :	18	: 1920-21 : Mason City E. to county line.
Cerro Gordo	: 15.55 :	65	: 1920-21 : Mason City S. to county line.
Clinton	: 17.56 :	30	: 1921-22 : Clinton city limits to a point 2 mi. W. of DeWitt. Excluding part within city limits of DeWitt.
Clinton	: 16.44 :	30	: 1922-23 : From point 2 mi. W. of DeWitt to W. county line. 13.61 mi. built 1922. Remainder in 1923.
Des Moines	: 4.89 :	34	: 1921 : W. from city limits of W. Burlington.

Des Moines	:	2.35 :	50	:	1921	:	W. from S.W. corner of W. Burlington
Dickinson	:	4.80 :	71	:	1921	:	Wilford S. to County line.
Floyd	:	8.66 :	18	:	1920	:	Charles City W. thru town of Floyd.
Floyd	:	9.29 :	18	:	1920-21	:	E. and W. of Rudd.
Floyd	:	2.58 :	18	:	1922	:	Thru Nora Springs to W. county line.
Greene	:	6.47 :	30 & 17	:	1920-21	:	N., E & W. of Jefferson city limits
Hancock	:	25.46 :	18	:	1921-22	:	approx. two miles each way.
						:	Entirely across county except city
						:	pavements in Britt and Garner.
						:	(Hutchins to West county line).
						:	(relocated 1935)
Humboldt	:	1.31 :	10	:	1920-21	:	
Johnson	:	3.64 :	6	:	1921	:	Thru town of Dakota City and Humboldt
Kossuth	:	11.26 :	18	:	1922	:	W. city limits of Ia. City W. thru
Linn	:	6.50 :	30	:	1920-21	:	Coralville.
						:	Algona to Wesley.
Marshall	:	5.93 :	30 & 14	:	1921	:	E. city limits of Cedar Rapids E. to
O'Brien	:	22.49 :	18	:	1920-21	:	"Seedling Mile". (0.61 miles relocate
						:	in 1931)
						:	North, S.E and W of city limits of
						:	Marshalltown approx. 1.5 miles each
						:	E & W. across county except for city
						:	pavements. (2 miles at N. side of
						:	Sheldon relocated in 1933).
Palo Alto	:	11.05 :	17	:	1920-21	:	Emmetsburg to Mallard except short
Polk	:	6.57 :	65	:	1920-21	:	gap at Des Moines River Bridge.
Polk	:	4.60 :	6	:	1920-21	:	Des Moines to Ankeny.
						:	Des Moines city limits on W. Grand
						:	Ave. W. to county line. Later abandon-
						:	ed as part of P.R. system in favor of
						:	present location of No. 6.
Polk	:	2.75 :	69 & 65	:	1921	:	Des Moines city limits S.E. to Co. line
Polk	:	4.78 :	60	:	1921	:	on Indianola Road.
						:	Des Moines city limits S.E. thru Levee
						:	to County line.
Polk	:	1.50 :	28	:	1921-22	:	Des Moines city limits S. to Ft. Des M.
Polk	:	0.99 :	28	:	1922	:	From Ft. Des Moines W. 1 mi.
Polk	:	20.26 :	60	:	1922-23	:	From N. city limits of Des Moines
						:	on 6th St. N.W. thru Polk City to
						:	Co. line S. of Madrid. 8.30 miles
						:	constructed in 1922.
Sioux	:	2.94 :	10	:	1920-21	:	Orange City to Alton.
Sioux	:	2.20 :	18	:	1921	:	Hull W. to #18 at Perkins.
Woodbury	:	14.00 :	20	:	1921	:	Sioux City to Merville.
Woodbury	:	2.73 :	230	:	1921	:	Sioux City towards Sergeants Bluff.
Woodbury	:	5.94 :	141	:	1922	:	Sioux City to Bronson.
Woodbury	:	7.02 :	75	:	1922	:	Salix to Sergeants Bluff.
Woodbury	:	0.92 :	20	:	1922	:	Thru Merville. (Later abandoned in
						:	favor of a route along the S. city
						:	limits.

Chronological list of Iowa DOT PCC research

1. HR/TR-7, Accelerated Testing of Highway Pavements, L. H. Csanyi, 1950
2. HR/TR-9, Performance of Various Thicknesses of Portland Cement Concrete Pavement, C. A. Elliott, 1950
3. HR/TR-10, Durability of Portland Cement Concrete, B. Brown, 1950
4. HR/TR-15, Limestone for Concrete Aggregates, J. Lemish, 1951
5. HR/TR-27, Control of Moisture in Highway Subgrades, M. G. Spangler, 1953
6. HR/TR-34, Thin Concrete Resurfacing, B. Myers, 1954
7. HR/TR-65, Study of Rock Materials in Southwestern Iowa, M. Morris, 1959
8. HR/TR-70, Properties of Carbonate Aggregates, R. S. Bear, 1959
9. HR/TR-78, Carbonate Mineralogy and Stratigraphy of Rocks of Iowa, D. L. Briggs, 1961
10. HR/TR-86, Relationship of Carbonate Aggregate to Serviceability of PCC, J. Lemish, 1962
11. HR/TR-92, Use of Sucrose and Dextrose in Portland Cement Concrete Paving, S. Roberts, 1963
12. HR/TR-110, Compositional and Mechanical Properties of Carbonate Rocks, D. Briggs, 1964
13. HR/TR-120, Concrete Popouts, R. Handy, 1965
14. HR/TR-118, Carbonate Aggregates for Portland Cement Concretes, J. Lemish, 1965
15. HR/TR-122, Concrete Pavement Studies, S. Roberts, 1965
16. HR/TR-125, Joint Heave Project (Neoprene Seals), S. Roberts, 1966
17. HR/TR-141, Deterioration of PCC Pavements, J. Lane, 1967
18. HR/TR-148, Investigation of Pavement Wear in Relation to Studded Tire Use, F. W. Walker, 1969
19. HR/TR-152, Measurements of Pavement Surface Variations, V. Marks, F. Walker, 1970
20. MLR-7103, Durability Study of Type II Cements, S. Carey, 1971
21. MLR-7102, A Study of the Relative Durability and Drying Shrinkage of Concrete Using Various Retarders, S. Carey, 1971
22. MLR-7101, An Investigation of the Chemical Method of Determining the Air Content of Hardened Concrete, M. Sheeler, 1971
23. MLR-7201, A Study of the Reliability of the ASTM C-666 Freeze-Thaw Test, V. Marks, 1972
24. HR/TR-165, Experimental Steel Fiber Reinforced Concrete Overlay -1, V. Marks, R. Betterton, 1972
25. MLR-7301, Method to Increase Durability of Reactive (D-Cracking) Coarse Aggregate in PCC, R. Less, 1973
26. HR/TR-168, Skid-Resistance of Concrete Pavements, B. Brown, R. Betterton, 1973
27. HR-1004, Corrosion of Steel in CRC Pavement, S. E. Roberts, 1974
28. MLR-7503, PCC Pavement Texturing, G. Calvert, 1975
29. MLR-7504, An Investigation of Concrete Setting Time, G. Calvert, 1975
30. MLR-7502, Evaluation of Argentine Nondestructive Test for Determining Concrete Compressive Strength, R. Less, 1976
31. MLR-7602, A Lab Investigation of the Accelerated Polishing Method for Determining Skid-Resistance Potential of Aggregate, G. Calvert, K. Isenberger, 1976
32. HR-1009, Bonded Thin-Lift, Nonreinforced PCC Resurfacing and Patching (MLR-77-2), J. Bergren, 1976
33. HR/TR-183, Fatigue Behavior of High Air Content Concrete, D. Y. Lee, F. Klaiber, 1976
34. MLR-7704, Iowa DOT's Experience With Recycling PCC Pavement and ACC Pavement, G. Calvert, 1977
35. MLR-7702, Bonded, Thin-Lift, Nonreinforced PCC Resurfacing, Bergren, Britson, Schroeder, 1977
36. MLR-7703, PCC Utilizing Recycled Pavement, J. Bergren, R. Britson, 1977
37. HR/TR-191, Bonded Thin-Lift Nonreinforced Portland Cement Concrete Resurfacing, M. Johnston, 1977
38. IR-717, PCC Over ACC (9 mi.), , 1977
39. HR-1010, Recycled Portland Cement Concrete Pavements, V. Marks, 1977
40. IR-710, Recycled PCC in Base Shoulder and Fillet Construction, , 1977
41. HR/TR-197, Fatigue Behavior of High Air Content Concrete, Phase II, D. Y. Lee, F. Klaiber, 1977
42. HR-506, Recycled Portland Cement Concrete Pavement in Iowa (NEEP 22), V. Marks, 1977

43. HR/TR-200, Fly Ash in Portland Cement Concrete Pavement - Monona County, O. Ives, 1978
44. HR/TR-201, Fly Ash in Portland Cement Concrete Pavement - Woodbury County, C. E. Leonard, 1978
45. HR-2011, Joints in PCC Pavement, V. Marks, 1978
46. HR/TR-203, Transverse Joint Sealing With Various Sealants, G. Hardy, 1978
47. HR/TR-206, Cement Produced From Fly Ash and Lime, W. Rippie, 1979
48. HR-1021, High Range Water Reducers in PCC Made With D-Crack Susceptible Coarse Aggregate, S. Moussalli, 1979
49. HR-513, PCC Concrete Overlay - Pottawattamie County, J. Lane, D. Smith, 1979
50. HR/TR-209, Pavement Surface on Macadam Base - Adair County, D. Lynam, 1979
51. HR-2008, Pulse Velocity Testing of D-Crack Susceptible Pavement, V. Marks, 1979
52. MLR-8001, Bonded PCC Resurfacing, J. Bergren, 1980
53. MLR-8002, Iowa Pore Index Test, J. Myers, W. Dubberke, 1980
54. HR-1024, Thin-Bonded Portland Cement Concrete Resurfacing (film), V. Marks, 1980
55. HR-2012, Fly Ash Pavement Sections, T. Cackler, 1980
56. HR/TR-225, Characterization of Fly Ash for Use in Concrete, T. Demirel, J. Pitt, 1980
57. HR/TR-224, Restoration of Frictional Characteristics on Older PCC Pavement, V. Marks, 1980
58. MLR-8106, Fly Ash Concrete Compressive Strength and Freeze-Thaw Durability, K. Isenberger, 1981
59. MLR-8508, Durability of Fly Ash Concrete Containing Class II Durability Aggregates, S. Moussalli, J. Myers, 1981
60. MLR-8102, Report on Fly Ash Variability, K. Isenberger, 1981
61. HR-2022, Iowa Pore Index Test, W. Dubberke, 1981
62. HR-1031, Fly Ash (Demo 59), K. Isenberger, 1982
63. HR/TR-244, Detection of Concrete Delamination by Infrared Thermography, B. Brown, 1982
64. HR/TR-250, A Nondestructive Method for Determining the Thickness of Sound Concrete on Older Pavements, V. Marks, 1982
65. HR/TR-258, Frost Action in Rocks and Concrete, T. Demirel, 1982
66. MLR-8304, Effect of Grooved Concrete on Curing Efficiency, J. Roland, 1983
67. MLR-8301, Bonding Agents for PCC and Mortar, B. Brown, 1983
68. HR-1035, Longitudinal Grinding and Transverse Grooving to Improve Friction and Profile, C. Potter, 1983
69. HR-520, Thin Bonded PCC Overlay, J. Lane, 1983
70. HR/TR-266, The Relationship of Ferroan Dolomite Aggregate to Rapid Concrete Deterioration, W. Dubberke, 1983
71. MLR-8406, Strength-Temperature Study of Fly Ash Concrete, B. Brown, 1984
72. MLR-8407, Evaluation of Fly Ash in Water-Reduced Paving Mixtures, B. Brown, 1984
73. MLR-8404, Durability of Concrete With Additives, J. Lane, S. Moussalli, 1984
74. MLR-8408, Reduction of D-Cracking Deterioration by Increasing Density of Concrete, S. Moussalli, 1984
75. MLR-8401, Curing Compound Efficiency on Grooved Concrete, M. Sheeler, 1984
76. HR-1042, PCC Joint Rehabilitation Techniques, V. Marks, 1984
77. HR/TR-165, Experimental Steel Fiber Reinforced Concrete Overlay -2, V. Marks, R. Betterton, 1984
78. IR-730, Joint Sealing - Without Backer Rope, Sta. 1060-1070, R. DeBok, 1984
79. HR/TR-271, Effects of Deicing Salt Compounds on Deterioration of PCC, J. M. Pitt, 1984
80. MLR-8509, Length Change of PCC Concrete Due to Moisture Content, V. Marks, 1985
81. MLR-8503, Fly Ash in PCC Base Mixes, S. Moussalli, 1985
82. MLR-8502, Fly Ash Effects on Alkali-Aggregate Reactivity, R. Allenstein, 1985
83. MLR-8505, Air Entrainment and PCC Durability, ---, 1985
84. HR/TR-272, Development of a Conductometric Test for Frost Resistance of Concrete, T. Demirel, B. Enustun, 1985
85. HR/TR-276, Transverse Joint Sealing With Improved Sealants, C. Cabalka, M. Callahan, 1985
86. HR/TR-281, Effects of Pavement Surface Texture on Noise and Friction Characteristics, J. Cable, 1985
87. HR-2030, PCC Preparation by Waterblast or Sandblast Cleaning, K. Jones, D. Smith, 1985
88. HR/TR-283, Pavement Texturing by Milling, V. Marks, 1985

89. HR/TR-286, Development of a Rational Characterization Method for Iowa Fly Ash, T. Demirel, 1985
90. MLR-8603, HMWM Resin for Sealing and Bonding of D-Cracked Concrete, J. Adam, 1986
91. MLR-8612, Determination of Tension Crack Development in Plastic PCC With Retarding Admixture, K. Jones, O. J. Lane, 1986
92. MLR-8611, Rapid Determination of Permeability of PCC by AASHTO T277-83, J. Nash, 1986
93. MLR-8601, Fly Ash in PCC Base, S. Moussalli, 1986
94. HR/TR-288, Field Evaluation of Bonded Concrete Resurfacing, Shiraz Tayabji, 1986
95. MLR-8602, Early Bond Str. Determined by 007 Bond Test and Direct Shear, O. J. Lane, 1986
96. HR/TR-291, Performance of Nongrouted Thin-Bonded PCC Overlay, J. Lane, W. Folkerts, 1986
97. HR-1045, Evaluation of Bond Retainage in PCC Overlays, R. Dankbar, 1986
98. HR-531, "Fast Track" PCC Overlay, J. Lane, 1986
99. HR-537, Evaluation of Bonded PCC Using Infrared Thermography (Inc HR-1045), R. Dankbar, 1986
100. HR-539, Automated Pavement Data Collection Equipment (Demo 960), J. Cable, Dr. K. Jeyapalan, 1986
101. HR-530, Pavement Undersealing, J. Lane, 1986
102. HR-2033, Retrofitting Load Transfer and Joint Ties (See HR-541), V. Marks, 1986
103. MLR-8706, Evaluation of Type I Cement Fast Track Concrete, K. Jones, 1987
104. MLR-8707, Early Strength of Class B, C and F Portland Cement Concrete, J. Grove, 1987
105. MLR-8704, Special Cements for Fast-Track Concrete (Phase I), K. Jones, 1987
106. MLR-8703, Field Evaluation of Class A Subbase Using Fly Ash, T. Parham, 1987
107. MLR-8709, Evaluation of Grouts for Use in Load Transfer Retrofitting or Reinforcing Bars, J. Nash, 1987
108. HR-538, Bettendorf Spruce Hills Drive Fast Track Paving, R. Holland, R. Merritt, 1987
109. HR/TR-299, Control of PCC Deterioration Due to Trace Compounds in Deicers (Ph 1,2, and 3), J. Pitt, 1987
110. HR-2037, ERES "Performance/Rehabilitation of Rigid Pavements", M. I. Dater, 1987
111. HR-541, Scott County Load Transfer Retrofitting (See HR-2033), ---, 1987
112. MLR-8801, Pavement Evaluation of Iowa 44 in Audubon and Guthrie Counties (D-Cracking), K. Jones and J. Nash, 1988
113. MLR-8806, Fine Sand for Use in PCC, K. Jones, 1988
114. MLR-8813, Fast Track Mixes for Iowa 100, Linn County, J. Grove, 1988
115. MLR-8815, Field Evaluations of Variations of Fast-Track Concrete (Transferred to HR-546), J. Grove, K. Jones, 1988
116. MLR-8812, Admixtures for Use as Retarders/Water Reducers in C-WR Mixes, ---, 1988
117. MLR-8807, Fly Ash Effect on Alkali-Aggregate Reactivity, K. Jones, 1988
118. MLR-8808, A Study of Fine Sand From Nine Mile Island at Dubuque, K. Jones, 1988
119. HR-546, Field Evaluation of Variations of Fast Track Concrete (MLR-88-15), J. Grove, 1988
120. HR-544, Accelerated Rigid Paving Techniques (FHWA 201), J. Bergren, V. Marks, 1988
121. MLR-8902, Pavement Evaluation Using the Road Rater(TM) Deflection Dish, C. Potter, 1989
122. MLR-8911, Precision and Accuracy Determination for PCC Core Testing - SHRP, K. Bharil, 1989
123. MLR-8905, Drying Shrinkage in PCC, K. Jones, 1989
124. MLR-8909, Durability of Durham Mine Stone in Fly Ash P.C. Concrete, K. Jones, 1989
125. MLR-8907, Evaluation of Alternative Methods to Obtain Coarse Aggregate Specific Gravity, K. Jones, C. Dalbey, 1989
126. MLR-8910, Evaluation of Class V Aggregate in Fly Ash Concrete Using the Wet/Dry Method, ---, 1989
127. HR/TR-318, Evaluation of Preformed Neoprene Joint Seals, R. Steffes, 1989
128. IR-731, Blank Band Tining Over Transverse Joints, T. Brady, 1989
129. MLR-9001, Evaluation of Test Method to Measure Response of Aggregate Cement-Fly Ash Combinations to D, ---, 1990
130. HR/TR-327, Evaluation of the Chemical Durability of Iowa Fly Ash Concretes, K. Bergeson, 1990
131. HR-2057, Early Strengths of PCC on U.S. 20 Near Fort Dodge, Dubberke, W., 1990
132. MLR-9101, Evaluation for Deterioration on U.S. 20 in Webster County, ---, 1991
133. HR/TR-337, Investigation of Rapid Thermal Analysis Procedures for Prediction of the Service Life of PCC Carbonate Coarse Aggregate, S. Schlorholtz, K. Bergeson, 1991

- 134.HR/TR-341, Bond Enhancement Techniques for PCC Whitetopping, G. Harris/B. Skinner, 1991
- 135.HR/TR-343, Noncorrosive Tie Reinforcing and Dowel Bars for Highway Pavement Slabs, M. Porter, 1991
- 136.MLR-9203, Affect of Fly Ash on Concrete Compressive Strength, C. Narotam, 1992
- 137.MLR-9206, Characteristics of Iowa Sand, C. Narotam, 1992
- 138.HR/TR-336, Thermogravimetric Analysis of Carbonate Aggregate to Predict Concrete Durability, W. Dubberke, 1992
- 139.HR/TR-355, The Role of Magnesium in Concrete Deterioration (+Executive Summary), R. Cody, P. Spry, A. Cody, 1992
- 140.MLR-9302, Preformed Phoenix EPDM Compression Joint Seals, R. Steffes, 1993
- 141.MLR-9306, Concrete Prism Testing, C. Narotam, 1993
- 142.MLR-9303, Effect of Cement and Sand Components on Expansion in ASTM P-214 Test, C. Narotam, 1993
- 143.HR/TR-358, Evaluation of Microcracking and Chemical Deterioration in Concrete Pavements, S. Schlorholtz, J. Amensen, 1993
- 144.HR-2065, Structural Contribution of Geogrids - Bridge Approach, C. Anderson, 1993
- 145.HR-2068, Recycling Old PCC on Grade with Manatt's Paradigm, Jasper County I-80, ----, 1993
- 146.HR-2066, Use of High Molecular Weight Methacrylate on the Burlington Bridge, ----, 1993
- 147.MLR-9405, Laboratory Testing of SHRP SPS-2 PCC Mixes, J. Grove, 1994
- 148.MLR-9409, Durability of Concrete Pavements Using Cements With Different Alkali Contents, C. Ouyang, 1994
- 149.MLR-9408, Coarse Aggregate Gradations for PCC, C. Ouyang, 1994
- 150.MLR-9406, Evaluation of Various Cements in Combination With Ground Slag or Class F Fly Ash, S. Gent, 1994
- 151.HR-2074, A Different Perspective for Investigation of PCC Pavement Deterioration, V. Marks, 1994
- 152.HR-559, Ultrathin PCC Overlays, J. Grove, J. Cable, 1994
- 153.HR-561, Bonded Overlay Grout Evaluation, J. Cable, 1994
- 154.HR-2072, Field Evaluation of Ash Grove Type IP Cement (I-29 in Pottawattamie County), J. Grove, 1994
- 155.MLR-9504, Vibration Study For Consolidation of Portland Cement Concrete, S. Tymkowicz, R. Steffes, 1995
- 156.MLR-9510, Instrumentation of Paver Vibrators, R. Steffes, 1995
- 157.MLR-9503, An Investigation of Concrete Maturity, C. Ouyang, 1995
- 158.MLR-9513, Freeze-Thaw Resistance of Cement With Excess Free Lime, T. Hanson, 1995
- 159.HR/TR-380, Maturity and Pulse Velocity Measurements for PCC Traffic Opening Decisions, J. Cable, 1995
- 160.HR-2076, Tine Impressions From PCC With RTV Rubber Molds, R. Steffes, 1995
- 161.HR-2078, Soff-Cut Centerline Joint and Potential Cracking Problem, R. Steffes, 1995
- 162.HR-563, Improved Gradation of PCC Mixtures, T. Hanson, 1995
- 163.HR-2077, I-80 Jasper PCC Test Sections, J. Lane, 1995
- 164.HR/TR-384, Expansive Mineral Growth and Concrete Deterioration, R. Cody, 1995
- 165.HR-1066, Evaluation of Mixing Time vs. Concrete Consistency and Consolidation, J. Cable, 1996
- 166.MLR-9601, Maturity of Concrete: Field Implementation, C. Ouyang, 1996
- 167.MLR-9602, Determination of Concrete Workability, R. Steffes, 1996
- 168.HR-1063, Pooled-Fund Study for Premature Rigid Pavement Deterioration, D. Gress, 1996
- 169.HR-1065, Durability of Highway Concrete Pavements (PCA 50 percent), J. Clifton, 1996
- 170.HR-2083, Granite Flour in PCC Pavement, T. Hanson, 1996
- 171.HR/TR-396, Image Analysis for Evaluating Air Void Parameters of Concrete, S. Schlorholtz, 1996
- 172.MLR-9702, Vibratory Effects in Reinforced PCC Pavement, B. Steffes, 1997
- 173.MLR-9705, Soffcut Sawed PCC Joint Ends, B. Steffes, 1997
- 174.MLR-9701, Mini Slump Cone Test Procedures and Precision, T. Hanson, 1997
- 175.HR/TR-409, Evaluation of Photoacoustic Spectroscopy for Quality Control of Cement, G. Norton, 1997
- 176.HR-1068, Evaluation of Paver Vibrator Frequency Monitoring and Concrete Consolidation, Jim Cable,

- 1997
- 177.HR/TR-403, Development of A Comprehensive Quality Incentive Program for PCC Paving, J. Cable, 1997
 - 178.HR/TR-406, Determine Initial Cause for Current Premature PCC Pave Deterioration, S. Schlorholtz, 1997
 - 179.HR/TR-408, Glass Fiber Composite Dowel Bars for Highway Pavement, M. Porter, 1997
 - 180.MLR-9703, Field Evaluation of QMC Strength Variability, S. Tymkowicz, 1997
 - 181.MLR-9708, Evaluation of the Duggan Test for Concretes Made of Different Types of Cements, T. Hanson, 1997
 - 182.MLR-9801, Early Sawing Influence on Sealant Bonding to Portland Cement Conc., B. Steffes, 1998
 - 183.MLR-9805, High Performance Concrete for Bridge Decks, C. Ouyang, 1998
 - 184.HR-1069, Field Evaluation of Alternative PCC Pavement Reinforcement Materials, Jim Cable, Max Porter, 1998
 - 185.HR/TR-420, Field Evaluation of Alternative Load Transfer Device Location in Low Traffic Volume Pavements, J. Cable/C. Greenfield, 1998
 - 186.MLR-9806, Evaluation of PCC Specification Changes Impact on Durability: 1992 to 1997 Core Study, T. Hanson, 1998
 - 187.MLR-9903, Plastic Air Versus Hardened Air by High Pressure Air Meter, T. Hanson/J. Hart, 1999
 - 188.MLR-9901, Evaluation of Performance Based Specifications for Blended Cements (ASTM C1157), T. Hanson/C. Ouyang, 1999
 - 189.MLR-9905, Field Evaluation of Water Reducers With Type I(SM) Cement, J. Grove/T. Hanson, 1999
 - 190.MLR-9604, Laboratory Study of the Leachate From Crushed PCC Base Materials, B. Steffes, 1999
 - 191.HR/TR-432, Ultrathin PCC Overlay Extended Evaluation, J. Cable, 1999
 - 192.MLR00-200005, Longitudinal Joint Forming In PCC Pavements, R. Steffes, 2000
 - 193.MLR00-200003, Evaluation of Long Term Durability of PCC Using Intermediate Sized Gravels to Optimize Mix Gradations, J. Hart, T. Hanson, 2000
 - 194.HR-1079, Two-Stage Mixing of Portland Cement Concrete, R. Steffes, 2000
 - 195.HR/TR-451, Investigation Into Improved Pavement Curing Materials and Techniques - Phase I and II, K. Wang/J. Cable, 2000
 - 196.HR-1080, Synthesis of Dowel Bar Research, M. Porter, 2001
 - 197.HR/TR-466, Evaluation of Unbonded Ultrathin Whitetopping of Brick Streets, J. Cable, 2001
 - 198.HR-2092, Hot-Poured Joint Sealant Bubbles, R. Steffes, 2001
 - 199.HR/TR-469, Reduction of Concrete Deterioration by Ettringite Using Crystal Growth Inhibition Techniques-Part II-Field Evaluation of Inhibitor Effectiveness, P. Spry/R. Cody, 2002
 - 200.MLR02-200201, Evaluating Properties of Blended Cements for Concrete Pavements, K. Wang (ISU), 2002
 - 201.HR-2094, Performance of Recycled PCC Base Material, R. Steffes, 2002
 - 202.MLR02-200203, PCC Curing Compound Performance - Phase I and II, R. Steffes, 2002
 - 203.HR/TR-478, Evaluation of Composite Pavement Unbonded Overlays (Installation and Maintenance of Weigh In Motion Detection System on Iowa 13 in Delaware County), P. Meraz/J. Cable, 2002
 - 204.HR/TR-479, Investigation Into Improved Pavement Curing Materials and Techniques: Part II (Phase III), J. Cable, 2002
 - 205.HR/TR-484, Materials and Mix Optimization Procedures for PCC Pavements, S. Schlorholtz/K. Wang, 2002
 - 206.HR/TR-480, Investigation of the Long-Term Effects of Concentrated Salt Solutions on Portland Cement Concrete, , 2002
 - 207.HR-2095, Crafcot Hot-Pour Sealant #34515, R. Steffes, 2002
 - 208.HR/TR-490, Stringless Portland Cement Concrete Paving, J. Cable, 2002
 - 209.HR-1081, Development of In-Situ Detection Methods for Material Related Distress (MRD) in Concrete Pavements, Phase II Extension, S. Schlorholtz/K. Wang, 2003
 - 210.HR-2097, Evaluation of Transverse Joint Forming Methods in PCC Pavement, R. Steffes, 2003
 - 211.MLR03-200301, Transverse Joint Forming in PCC Pavements, R. Steffes, 2003
 - 212.HR/TR-505, Improving PCC Mix Consistency and Production by Mixing Improvements, V. Schaefer, 2003

- 213.MLR04-200402, Evaluation of Recycled Concrete Aggregate for Use as Base, Subbase and Granular Surfacing, K. Jones, 2004
- 214.HR/TR-510, Laboratory Study of Structural Behavior of Alternative Dowel Bars, M. Porter - J. Cable - F. Fanous - B. Coree, 2004
- 215.HR/TR-511, Design and Construction Procedures for Concrete Overlay and Widening of Existing Pavements, J. Cable -H. Ceylan - F. Fanous, 2004
- 216.HR/TR-512, Measuring Pavement Profile at the Slip Form Paver, J. Cable, 2004
- 217.HR/TR-520, Evaluation of Dowel Bar Retrofits for Local Road Pavements, J. Cable / M. Porter, 2004
- 218.HR/TR-532, Evaluation of Transverse Joint Forming Methods in PCC Pavement, J. Cable, 2005
- 219.MLR05-200501, Investigation of High Performance Concrete Pavements, T. Hanson / K. Merryman, 2005
- 220.HR/TR-537, Iowa Data Collection and Analysis for the 2005/2006 National Surface Characteristics Field Experiment Plan, E.T. Cackler / J. Cable / D. Harrington, 2005
- 221.HR/TR-538, Using Scanning Lasers for Real-Time Pavement Thickness Measurement, E. Jaselskis / R. Walters / E.T. Cackler, 2005
- 222.MLR05-200502, Air and Permeability of Old PCC Pavements, T. Hanson, 2005
- 223.HR-2104, Performance of Transverse Joints in PCC Pavement Without Sealing, E. Engle/K.Jones, 2006
- 224.HR/TR-554, Performance and Evaluation of Concrete Pavement Granular Subbase, D. White, 2006

Appendices

- Table 1 - Iowa DOT Specification History 1925 to 2005 pages 67-70
- Table 2 - Iowa DOT Mix Design History pages 71-73
- Table 3 - Iowa DOT Primary Design History page 74
- Table 4 – Iowa DOT Interstate Design History page 75
- Table 5 – Iowa's Bonded PCC Overlays on State Routes page 76
- Table 6 – Iowa's Unbonded PCC Overlays on State Routes page 77
- Table 7 – Iowa's Whitetopping on State Routes page 78
- Table 8 – Smoothness Incentive Tables page 79
- Table 9 – Thickness Incentive Tables pages 80-81

Table 1 – Iowa DOT Specification History 1925 to 2008

Spec Book	Aggregate	Materials and Mix Design	Curing and Opening	Smoothness and Thickness	Finishing and Texture	Equipment
1925	CLASS ONE - GRANITE, QUARTZITE CLASS TWO - CLEAN GRAVEL OR LIMESTONE WITH FRENCH COEFFICIENT OF WEAR 5 or 6 CLASS THREE - PIT RUN GRAVEL 1927 - CLASS V AGGREGATE	CEMENT MEETS ASTM C-9 PROPORTIONAL MIX DESIGN SLUMP 1½ INCHES	BURLAP AND 2 INCHES WET EARTH OR SAND COVERING FOR 10 DAYS CACL AFTER OCT 15TH OPENING TIME 21 DAYS	CHECKED WITH 10-FOOT STRAIGHTEDGE. DEPRESSIONS OR HIGH SPOTS >1/4 INCH MUST BE CORRECTED	FINISH LONGITUDINALLY WITH 12-FOOT x 12-INCH x 3-INCH WOOD FLOAT 8 to 10 INCH BELT WORKED TO MAKE A GRITTY TEXTURE	
1930		SLUMP 1 INCH WATER NOT EXCEED 5.5 GAL/BAG	BURLAP 24 HRS AND 6 DAY CURING WITH EARTH, SAND, IMPERVIOUS COATINGS,PAPER, OR MATS	CHECKED WITH 10-FOOT STRAIGHTEDGE. DEPRESSIONS OR HIGH SPOTS >1/4 INCH MUST BE CORRECTED WITH CARBORUNDUM BRICK		EXPANSION JOINT INSTALL PREMOULDED BITUMINOUS MATERIAL 1 MINUTE MIX TIME
1933	SODIUM SULPHATE SOUNDNESS TEST - 5 CYCLES F/T 16 CYCLES	SLUMP 2 INCH	BURLAP 20 HRS AND 6-DAY CURING WITH EARTH, SAND, IMPERVIOUS COATINGS,PAPER, OR MATS - CONTRACTOR OPEN IN 7 DAYS	CHECKED WITH 10-FOOT STRAIGHTEDGE DEPRESSIONS OR HIGH SPOTS >1/8 INCH MUST BE CORRECTED WITH CARBORUNDUM BRICK		LONGITUDINAL JOINT BY METAL PARTING STRIP
1937		ABSOLUTE VOLUME MIX DESIGNS 1-4 AND V	500 PSI MOR AND 7 DAYS NORMAL PORTLAND, 3 DAYS HIGH EARLY		HEAVY 10- FOOT STRAIGHTEDGE PARALLEL TO CL	CENTRAL MIXED TRUCK DELIVERY or READY MIX CONCRETE 27E MIXER
1948	REFERENCE TO CLASS DELETED SODIUM SULPHATE SOUNDNESS TEST - 10 CYCLES F/T 16 CYCLES LA ABRASION 35% GRAVEL 45% STONE	CEMENT ASTM C150 TYPE I, IA, III SLUMP ½ INCH TO 1½ INCH MIX DESIGNS 1-4A, 1-4B, 1-4C (STANDARD) AND V	500 PSI MOR AND 7 DAYS NORMAL PORTLAND, 3 DAYS HIGH EARLY, TYPE B 14 & 7 DAYS TYPE A			MECHANICAL FINISHING MACHINE TRANSVERSE JOINTS 27E AND 34E MIXERS

Table 1 – Iowa DOT Specification History 1925 to 2008

Spec Book	Aggregate	Materials and Mix Design	Curing and Opening	Smoothness and Thickness	Finishing and Texture	Equipment
1952		PLASTIC AIR CONTENT 5 TO 7% CLASS V, 3 TO 5% OTHER			METAL FLOAT MAY BE USED IF WEIGHT EQUAL TO WOOD, THEN STRIKE OFF WITH HEAVY 10 FOOT STRAIGHTEDGES AFTER BELTING, FINAL FINISH WET BURLAP (2 LAYER) OR CARPET DRAG-UNIFORM FREE OF GROOVES OVER 1/16 INCH	ALLOW SINGLE-LANE WIDTH PAVING (SMALL SLIPFORM PAVERS) VIBRATORS MINIMUM 3500 VPM/S 16E, 27E AND 34E MIXERS
1956		AIR CONTENT 5 TO 7% CLASS V, 4 TO 6% OTHER				SAWING LONG JT CONTRACTOR OPTION WITHIN 7 DAYS 80 FOOT TRANSVERSE SAWED WITHIN 24 HRS. OTHERS WITHIN 3 DAYS LONG JT SAWED WITHIN 5 DAYS
1960		AIR CONTENT 6%, ALL		1960 SMOOTHNESS BPR -80 PERCENTILE OF OTHER CONCRETE PAVEMENTS		
1964	1971 - AGGREGATE DURABILITY CLASS SYSTEM CLASS 2 PAVEMENT CLASS 1 STRUCTURES	CLASS A, B AND C MIXES		CHECKED WITH 10-FOOT STRAIGHTEDGE. DEPRESSIONS OR HIGH SPOTS >1/8 INCH MUST BE CORRECTED WITH CARBORUNDUM BRICK THICKNESS DEFICIENCY BANDS 0.15 INCH OR LESS 100% 1 INCH 0 TO 10% PAY		PLACEMENT BY STANDARD OR SLIPFORM PAVEMENT CONSTRUCTION OR STATIONARY MIXER 60 SECS. MIX TIME LESS THAN 5 YD3, 90 SECS. FOR MORE THAN 5 YD3
1972		1974 - WATER REDUCER (WR) MIXES ADDED CEMENT AASHTO M85 10/1974 NA20 EQ. 0.75%, 0.60% FOR CL. V.			6/1976 - TURE, COARSE CARPET OR BURLAP AND TRANSVERSE TINE VARY 1/8 INCH TO 3/16 INCH WIDE AT ¾ INCH CENTERS	

Table 1 – Iowa DOT Specification History 1925 to 2008						
Spec Book	Aggregate	Materials and Mix Design	Curing and Opening	Smoothness and Thickness	Finishing and Texture	Equipment
1977	11/1982 CLASS 3 INTERSTATE CLASS 2 PRIMARY CLASS 1 STRUCTURE 11/1983 CLASS 2 STRUCTURE	CEMENT NA20 EQ. 0.75% 1/1979 C-6WR MIX ADDED		1977 – 10-FOOT STRAIGHTEDGE 1/8 INCH IN 10 FOOT HIGH SPOTS SMOOTHED BY GRINDING 12/1981 – 25-FOOT PROFILEGRAPH - 100% PAY FOR 15 IN/MI OR LESS		VIBRATORS MINIMUM OF 7000 VPM'S
		2/1984 - 15% FLY ASH CONTRACTORS OPTION 11/1982 CEMENT NA20 EQ. 0.90%	1/1986 – CERTIFIED PLANT INSPECTION	1/1985 – CERTIFIED TESTING BY CONTRACTOR, INTERSTATE NOT EXCEED 15 IN/MI 5/1985 - INCENTIVE 2% INTERSTATE 2 IN/MI AND NON INTERSTATE 4 IN/MI 12/1989 - 100% PAY FOR 12 IN/MI OR LESS INCENTIVE 4% INTERSTATE 2 IN/MI AND 2% NON INTERSTATE 4 IN/MI on subgrade, 3 IN/MI on GSB	12/1987 TRANSVERSE 1½ INCH CENTERS 12/1989 TRANSVERSE ¾ INCH CENTERS	SUPPLEMENTARY VIBRATION AT BASKETS
1984						
1992	1/1992 CLASS 3 INTERSTATE CLASS 3 PRIMARY CLASS 2 STRUCTURE	9/1994 - PLASTIC AIR CONTENT 7 ± 1% 1/1995 – 20% FLY ASH, 5- 10% TYPE IP 10/1996 – CEMENT S03 =3%, NA20 EQUIV. =0.60% TYPE II REQUIRED		11/1993 - INCENTIVE 3 IN/MI OR LESS, 100% 3.1 TO 7 IN/MI 2/1994 – THICKNESS INCENTIVE QUALITY INDEX FOR LOT 1.25 OR MORE 103%	1992 TURF OR COARSE CARPET (BURLAP DELETED)	9/1994 VIBRATORS RANGE 5000 TO 8000 VPM'S 9/1994 SUPPLEMENTARY VIBRATION DELETED

Table 1 – Iowa DOT Specification History 1925 to 2008

Spec Book	Aggregate	Materials and Mix Design	Curing and Opening	Smoothness and Thickness	Finishing and Texture	Equipment
1997		11/1997 TYPE IS, I(SM) OR 35% GGBFS OPTION WITH 10% FLY ASH	1997 - MATURITY METHOD OF OPENING AT CONTRACTOR'S OPTION	4/1998 - THICKNESS INCENTIVE BASED ON PROJECT AS ONE LOT	10/1998 OPTION LONGITUDINAL ¾ INCH SPACED or TRANSVERSE RANDOM ¾ INCH to 1¼ INCH	
2001		10/1999 – AIR CONTENT 7% +1.5%/-1% 2000 - QMC MIX DESIGN BY CONTRACTOR 10/2000 - PLASTIC AIR CONTENT 6%+ PAVER LOSS +1.5%/-1% C-5 AND C-6 NOT ALLOWED INTERSTATE AND PRIMARY 10/2000 – FLY ASH 15% FOR ALL CEMENT TYPES 4/2004 – CEMENT MEET ASTM C150, NA20 EQUIV. ±0.60% 10/2004 – FLY ASH 20% FOR ALL CEMENT TYPES 4/2009 – PLASTIC AIR CONTENT 8±2%			10/2005 BURLAP ADDED TO MICROTEXTURE OPTION	2001 VIBRATORS RANGE 4000 TO 8000 VPM'S

Table 2 - Iowa DOT Mix Design History - Standard Pavements						
Up to 1929						
Class	Sand Passing 1/4" screen	Proportions Cement Pit run gravel			Cement Content Barrels/yd3	lbs/yd3
A or C	55%	I sack	4.0 ft3		1.68	632
	up to 65%	I sack	3.75 ft3		1.80	677
	up to 75%	I sack	3.5 ft3		1.92	722
	up to 85%	I sack	3.25 ft3		2.00	752
Water - enough to make consistency requiring considerable tamping.						
Air - n/a						
1930 Standard Concrete Pavement						
Mix #	Proportions Cement:Sand:Coarse		Max. Agg Size, in.		Cement Content Barrels/yd3	lbs/yd3
1	1:1.718:3.488		1.5		1.63	613
2	1:1.946:2.929		2.5		1.71	643
3	1:2.067:2.526		2.5		1.78	669
4	1:2.170:2.170		2.5		1.85	696
5	1:2.258:1.848		2.5		1.92	722
6	1:2.315:1.543		2.5		2.00	752
Water (max) - 5.5 gallons/bag						
Air - n/a						
1937 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Cement Content Barrels / yd3	lbs/yd3
1	0.115873	0.169510	0.235824	0.478793	1.63	613
2	0.121544	0.177806	0.280260	0.420390	1.71	643
3	0.126459	0.184996	0.309845	0.378700	1.78	669
4	0.131562	0.192462	0.337988	0.337988	1.85	696
Water (max) - 5.5 gal/bag = 0.488						
Air - n/a						
1948 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Cement Content Barrels / yd3	lbs/yd3
1C	0.10662	0.155975	0.258047	0.479358	1.63	613
2C	0.109446	0.160109	0.292178	0.438267	1.71	643
3C	0.113794	0.166468	0.323882	0.395858	1.78	669
4C	0.117952	0.172552	0.354748	0.354748	1.85	696
Water (max) - 5.634 gal/bag = 0.500						
Air - n/a						

Iowa DOT Mix Design History - Standard Pavements (cont'd)						
1952 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-1-Ax	0.106611	0.143961	0.248300	0.461128	0.04	564
C-2-Ax	0.109446	0.147789	0.281106	0.421659	0.04	579
C-3-Ax	0.113794	0.153660	0.311646	0.380900	0.04	602
C-4-Ax	0.117952	0.159276	0.341336	0.341386	0.04	624
Water (max) - 5.25 gal/bag = 0.466						
1956 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-1-A	0.106611	0.152989	0.241640	0.448760	0.05	564
C-2-A	0.110202	0.159217	0.272232	0.408349	0.05	583
C-3-A	0.114172	0.163840	0.302395	0.369593	0.05	604
C-4-A	0.118330	0.169808	0.330931	0.330931	0.05	626
C-5-A	0.123056	0.176589	0.357695	0.292660	0.05	651
C-6-A	0.127782	0.183371	0.383308	0.255539	0.05	676
C-8-A	0.138934	0.199375	0.428184	0.183507	0.05	735
Water (max) - 5.25 gal/bag = 0.466						
1960 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-1	0.106611	0.152989	0.236640	0.443760	0.06	564
C-2	0.110202	0.159217	0.267662	0.403992	0.06	583
C-3	0.114172	0.163840	0.297395	0.364593	0.06	604
C-4	0.118330	0.169808	0.325931	0.325931	0.06	626
C-5	0.123056	0.176589	0.352948	0.287867	0.06	651
C-6	0.127782	0.183371	0.378308	0.250539	0.06	676
Water (max) - 5.5 gal/bag = 0.488						
1964 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-2	0.110202	0.158144	0.267662	0.403992	0.06	583
C-3	0.114172	0.163840	0.297395	0.364593	0.06	604
C-4	0.118330	0.169808	0.325931	0.325931	0.06	626
C-5	0.123056	0.176318	0.352948	0.287867	0.06	651
C-6	0.127782	0.183771	0.378308	0.250539	0.06	676
Water (max) - 5.15 gal/bag = 0.457						

Iowa DOT Mix Design History - Standard Pavements (cont'd)						
1972 Standard Concrete Pavement						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-2	0.110202	0.148144	0.272662	0.408992	0.06	583
C-3	0.114172	0.153840	0.301895	0.370093	0.06	604
C-4	0.118330	0.159808	0.330931	0.330931	0.06	626
C-5	0.123056	0.166318	0.358448	0.292367	0.06	651
C-6	0.127782	0.173771	0.384308	0.254539	0.06	676
Water (max) - 5.5 gal/bag = 0.488						
1974 Water reduced mixes added						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-3WR	0.105038	0.142614	0.311557	0.380791	0.06	556
C-4WR	0.108864	0.147180	0.341978	0.341978	0.06	576
1979 Water reduced mixes added						
C-6WR	0.121393	0.164411	0.392518	0.261678	0.06	642
Water (max) 0.489						
1987 to Present Water Reduced Mixes						
Mix #	Cement	Water	Fine	Coarse	Air	Cement lbs/yd3
C-3WR	0.108	0.146	0.309	0.377	0.06	571
C-4WR	0.112	0.151	0.339	0.338	0.06	593
C-5WR	0.117	0.158	0.366	0.299	0.06	619
C-6WR	0.121	0.163	0.394	0.262	0.06	640
Water (max) 0.489						

Table 3. Iowa DOT's Primary Design History

Year	Design Width	Depth	Subgrade Treatment	Longitudinal JT	Contraction JT	Expansion JT
1917 to 1921	18'	6" 8-7-8	Trimmed by the Highway Commission	None	None	
1921 to 1934	18'	10-7-10	Bituminous paper (1933)	5/8" X 5' @4' C-C	None	Mastic 100'
1935 to 1949	20'	10-7.5-10 10-8-10		1/2" X 12" @2' C-C		
1951 to 1957	22'	10-8-10		5/8" X 11'3" @6' C-C Alternating Sides	Longitudinal bars 4 – 5/8" continuous 9" from center and edge	
1953 to 1956	(3' Widening Projects)					
1958 to 1971	22' 24" 1960	8" – 10" 10"	Bituminous paper or plastic (1960) or uniform moist (1964)	L-1	C – 20'	
1971 to 1988	24'	10" 4" ATB or CTB . (If AADT >700 or on grade)	Uniform moist or plastic (1984)	L-1	C – 20' CD - 20' if ADTT>700 TPD up to 1994 straight up to 1979, 6:1 skew 1980 to 2005	
1989 to Present	24' 26' (1990 and Later)	10" -11" 6"-9" GSB		L-1	CD - 20' if ADTT>300 TPD to 1995 and later CD – 20' straight (since 2005)	

Table 4. Iowa DOT's Interstate Design History

Year	Width	Design Depth	Longitudinal JT	Contraction JT	Mesh
1958 to 1965	24'	10" PCC 4" GSB	5/8" X 30" @3'	C - 76.6' 1 1/4" X 18" @12' C-C	#4 – 6" X 12" 11.5' x 16' mat
1966 to 1968	24'	8" CRC 4" GSB			#5 bar on 6" C-C 23.6' wide
1969 to 1976	24'	8" CRC 4" (ATB OR CTB)			#5 bar on 6" C-C 23.6' wide
1976 to 1984 (I-380)	24'	10" PCC 4" CTB or ECB	L-1, L-2	CD – straight	
1979 I-80 Adair whitetopping	24'	10" PCC	L-1	CD – straight	
1981 I-80 Adair whitetopping half-width	12.5'	10" PCC		CD – skewed	
1985 to present	25'	10" TO 12" 9" GSB	L-1, L-2	CD – skewed (1981 to 2004)	
	26' (1988 to present)			CD – straight (2005 to present)	

Table 5 - Iowa's Bonded PCC Overlays on State Routes

COUNTY	PROJECT NO.	LENGTH	S.Y.	THICKNESS	ORIG. CONST.	OVERLAY	COST/ S.Y.	CONTRACTOR
Pottawattamie	I-EACIR-80-1(126)	4.492	63,246	3.0	1966	1979	6.91	KCC
Dallas (On Iowa 141 from U.S. 169 E to Woodward)	FR-141-6(29)	3.4	46,056	4.5	1941	1983	9.29	FCC
Poweshiek (I-80 from 1 mile east of Iowa 146 east to 1.25 miles east of U.S. 63)	IR-80-5(106)	9.084	127,900	4.0	1964	1984	8.87	MAN
Buena Vista (U.S. 71 - Jct. Iowa 3, to Jct. Iowa 10)	FR-71-7(32)	6.800	95,773	4.0	1949	1986	7.99	CPC
Pottawattamie (I-80 [WB] Shelby intrchg. east to Avoca intrchg.)	IR-80-1(167)	4.134	53,600	6.0	1966	1988	16.15	IFJ
Scott (I-280 [SB] from Iowa 22 north to U.S. 6)	IR-280-9(97)	7.250	137,390 23,072	5.0 Cl.C 5.0 Cl.F	1972	1989 1989	10.74 12.13	CVC
Scott (I-280 [NB] from I-80 SE to Mississippi River)	IR-280-8(98)	7.230	142,863 19,212	5.0 Cl.C 5.0 Cl.F	1972	1990 1990	10.22 12.83	VCC
Hamilton (I-35 N of Hamilton County Road D-41 intrchg. N to intrchg. Iowa 928)	IR-35-5(54)133--12-40	4.022	65,259	5.0 Cl.C	1967	1991	10.80	FCC
Hamilton (I-35 from 2 mi. N of Iowa 175 intrchg. N to N of Hamilton County Road D-41 intrchg.)	IR-35-5(56)133--12-40	6.052	111,169 8,266	5.0 Cl.C 3.0 Cl.C	1967	1992	11.38	IFJ
Franklin (3 miles W of Franklin County Road S-41 east 1.8 miles, and at I-35 intrchg.)	NHS-3-5(50)—19-35	2.900	40,260	3.0 Cl.F Prep.	1970	1994	10.92 3.30	CVC

Contractor Key:

CFC - Cedar Falls Construction Co., Waterloo, Iowa
 CPC - Central Paving Corp., Indianola, Iowa
 CVC - Cedar Valley Corp., Waterloo, Iowa
 FCC - Fred Carlson Co., Decorah, Iowa
 HCC - Hallett Construction Co., Boone, Iowa
 IFJ - Irving F. Jensen Co. Inc., Sioux City, Iowa
 KCC - Koss Construction Co., Des Moines, Iowa
 KCU - K. Cunningham Construction, Cedar Falls, Iowa
 MAN - Manatt's Inc., Brooklyn, Iowa
 MPC - M. Peterson Construction Co., Des Moines, Iowa
 RCC - Reilly Construction Co. Inc., Ossian, Iowa
 VCC - Valley Construction Co., Rock Island, Ill.

Table 6 – Iowa's Unbonded PCC Overlays on State Routes

2009

<u>County</u>	<u>Project No.</u>	<u>Length (Miles)</u>	<u>Orig. Const.</u>	<u>Overlay Const.</u>	<u>Orig. Cost/SY</u>	<u>Overlay Cost/SY</u>	<u>Orig. Thick/ Width</u>	<u>Overlay Thick/ Width</u>	<u>Traffic Count (Vpd)</u>	<u>Interface</u>	<u>Cont.</u>
Delaware	STP-13-2(33)2C-28	9.545		2002		8.29		3.5-4.5"x28'	1300	Existing HMA	FCC
(Iowa 13 from NCL of Manchester N to Iowa 3)											
Sac	STP-175-4(13)—2C-81	10.26		2007				4.5"x28'		Existing HMA	CVC
Woodbury	IM-29-6(183)132—13-97	14.02		2008				9"x26'		Existing HMA	CVC
Osceola	STPN-9-2(21)—2J-72	8.81		2009				5.5"x32'		Existing HMA	FLN
Worth	STPN-65-9(18)—2J-98	11.33		2009				5"x32'		Existing HMA	FLN
Fremont (NB)	IMX-29-1(75)16—02-36	4.20		2009				9"x26'		1" HMA	CVC
Mills (NB)	IMX-29-2(65)38—02-65	6.00		2009				9"x26'		Existing HMA	CVC

Contractor Key:

CFC - Cedar Falls Construction Co., Waterloo, Iowa
CPC - Central Paving Corp., Indianola, Iowa
CVC - Cedar Valley Corp., Waterloo, Iowa
FCC - Fred Carlson Co., Decorah, Iowa
HCC - Hallett Construction Co., Boone, Iowa
IFJ – Irving F. Jensen Co. Inc., Sioux City, Iowa
KCC - Koss Construction Co., Des Moines, Iowa
KCU - K. Cunningham Construction, Cedar Falls, Iowa
MAN - Manatt's Inc., Brooklyn, Iowa
MPC - M. Peterson Construction Co., Des Moines, Iowa
RCC – Reilly Construction Co. Inc., Ossian, Iowa
VCC - Valley Construction Co., Rock Island, Ill.

Table 7 - Iowa's Whitetopping on State Routes

2009

<u>County</u>	<u>Project No.</u>	<u>Length Miles</u>	<u>Year Overlay Const.</u>	<u>Overlay Cost/SY</u>	<u>Overlay Thickness and Width</u>	<u>Surface Preparation</u>	<u>Traffic Count (Vpd)</u>	<u>Contractor</u>
Adair Inlay		5.000	1979		10"x24'	Removed 8" AC surface	21000	
(I-80 [WB] milepost 93.86 to milepost 97.25)								
Adair Inlay		8.100	1981		10"x12.5'	Removed 10" AC surface	21000	
(I-80 [WB] (driving lane only) milepost 85.75 to milepost 93.86)								
Iowa	STP-21-3(10)--C-48	7.000	1994	Various	Var. x24'	Mill, cold-in place, patching	2400	MAN
(On Iowa 21 Jct. U.S. 6 N 7.0 miles)								
Montgomery	NHSN-71-2(36)—2R-69	12.5	2006		8" x 32'	Mill 3"		MAN
Cass	NHSN-71-3(42)—2R-15	10.75	2007		8" x 32'	Mill 3"		FLN
Bremer	NHSN-218-8(109)—2R-09	7.64	2009		8" x 32'	Mill 1.5"		MAN

Contractor Key:

CFC - Cedar Falls Construction Co., Waterloo, Iowa
CPC - Central Paving Corp., Indianola, Iowa
CVC - Cedar Valley Corp., Waterloo, Iowa
FCC - Fred Carlson Co., Decorah, Iowa
HCC - Hallett Construction Co., Boone, Iowa
IFJ - Irving F. Jensen Co. Inc., Sioux City, Iowa
KCC - Koss Construction Co., Des Moines, Iowa
KCU - K. Cunningham Construction, Cedar Falls, Iowa
MAN - Manatt's Inc., Brooklyn, Iowa
MPC - M. Peterson Construction Co., Des Moines, Iowa
RCC - Reilly Construction Co. Inc., Ossian, Iowa
VCC - Valley Construction Co., Rock Island, Ill.

Table 8 - Smoothness Incentive Tables

Smoothness Incentive Table 1994 to 2008 – 0.2” Blanking Band
(from Iowa DOT Standard Specifications April 2008)

INITIAL PROFILE INDEX	SINGLE LIFT PAVEMENTS	
Inches Per Mile Per Segment	Primary	Nonprimary
	Dollars Per Segment	Dollars Per Segment
0-1.0	700	300
1.1-2.0	600	250
2.1-3.0	450	200
3.1-7.0	Unit Price	Unit Price

Smoothness Incentive Table 2008 to Present – Zero Blanking Band
(from Iowa DOT Standard Specifications October 2008)

Table 2317.05A: Schedule for Adjustment Payment for PCC Pavements (0 inch blanking band)			
Profile Index For Greater than 45 mph	Profile Index For 45 mph or Less and Ramps	Dollars per 0.1 mile (161 m) segment per lane	
Inches per Mile (mm/km)	Inches per Mile (mm/km)	Interstate and Multi-Lane Divided Segments	Other Primary Segments
22.0 or less (345 or less)	25.0 or less (395 or less)	+950.00	+850.00
22.1 to 23.5 (346 to 370)		+800.00	+650.00
23.6 to 26.0 (371 to 410)	25.1 to 30.0 (396 to 475)	+600.00	+450.00
26.1 to 40.0 (411 to 630)	30.1 to 65.0 (476 to 1025)	0.00	0.00
40.1 to 45.0 (631 to 710)	65.1 to 70.0 (1025 to 1105)	-600.00	-450.00
45.1 or more (711 or more)	70.1 or more (1105 or more)	0.00*	0.00*
* Corrective work required.			

Table 9 – Thickness Incentive Tables (pg 1 of 2)

Thickness Incentive Table 1964 to 1990

Band	Deficient from Design Thickness	8 inch	9 inch	10 inch
1a	> Design to 0.15 inch	100	100	100
1b	0.15 to 0.25 inch	95	96	96
2	0.25 to 0.5 inch	91	92	93
3	0.5 to 0.75 inch	85	87	88
4	0.75 to 1.0 inch	80	82	84
5	> 1.0 inch	0 to 10	0 to 10	0 to 10

Thickness Incentive Table 1991 to 1993

Band	Deficient from Design Thickness (T)	percent Contract Unit Price
1	All cores greater than T	105
2	0.15 to 0.25 inch	102
3	0.25 to 0.5 inch	100
4		95
5	0.25 to 0.5 inch	85
6	0.55 to 0.75 inch	75
7	0.80 to 1.0 inch	60
8	> 1.0 inch	0

Thickness Incentive Table 1994 to 1997

percent Contract Unit Price	Quality Index Range
103	1.25 or more
101	0.86 to 1.24
100	0.41 to 0.85
98	0.20 to 0.40
95	0.00 to 0.19
90	-0.25 to -0.01
80	-0.40 to -0.26
70	-0.41 or less

Table 9 – Thickness Incentive Tables (pg 2 of 2)

Thickness Incentive Table 1998 to Present
(from Iowa DOT Standard Specifications April 2008)

Payment Schedule			
Thickness Index Range [English (Metric)]	Percent Payment	Thickness Index Range [English (Metric)]	Percent Payment
0.00 or more (0.00 or more)	103	-0.56 to -0.60 (-13.98 to -15.24)	91
-0.01 to -0.05 (-0.01 to -1.27)	102	-0.61 to -0.65 (-15.25 to -16.51)	90
-0.06 to -0.10 (-1.28 to -2.54)	101	-0.66 to -0.70 (-16.52 to -17.78)	89
-0.11 to -0.15 (-2.55 to -3.81)	100	-0.71 to -0.75 (-17.79 to -19.05)	88
-0.16 to -0.20 (-3.82 to -5.08)	99	-0.76 to -0.80 (-19.06 to -20.32)	87
-0.21 to -0.25 (-5.09 to -6.35)	98	-0.81 to -0.85 (-20.33 to -21.59)	86
-0.26 to -0.30 (-6.36 to - 7.62)	97	-0.86 to -0.90 (-21.69 to -22.86)	85
-0.31 to -0.35 (-7.63 to -8.89)	96	-0.91 to -0.95 (-22.87 to -24.13)	84
-0.36 to -0.40 (-8.90 to -10.16)	95	-0.96 to -1.00 (-24.14 to -25.40)	83
-0.41 to -0.45 (-10.17 to -11.43)	94	-1.01 to -1.05 (-25.41 to -26.67)	82
-0.46 to -0.50 (-11.44 to -12.70)	93	-1.06 to -1.10 (-26.68 to - 27.94)	81
-0.51 to -0.55 (-12.71 to -13.97)	92	-1.11 or less (-27.95 or less)	80

References

- ¹ Welp, T.L. and McElherne, T.E., Iowa Field Conference on D-Cracking, Iowa State Highway Commission, 1967
- ² Myers, J. and Dubberke, W., Iowa Pore Index Test, MLR-8002, Iowa Department of Transportation, 1980
- ³ Dubberke, W., The Relationship of Ferroan Dolomite Aggregate to Rapid Concrete Deterioration, 1983
- ⁴ Dubberke, W., Thermogravimetric Analysis of Carbonate Aggregate to Predict Concrete Durability, HR/TR-336, 1992
- ⁵ Bergren, J. and Britson, R., PCC Utilizing Recycled Pavement, Iowa Department of Transportation, 1977
- ⁶ Crum, R.W., Design of Concrete Mixtures, Iowa Highway Commission, 1927
- ⁷ Lane, J., "Fast-Track" PCC Overlay, Iowa Department of Transportation, 1986
- ⁸ Tymkowicz, S., Field Evaluation of QMC Strength Variability, Iowa Department of Transportation, 1997
- ⁹ Moussalli, S. and Riley, R., Special Report on Alkali-Aggregate Reactivity in Iowa, Iowa Department of Transportation, 1980
- ¹⁰ Jones, K. and Putherickal, J., Evaluation of Deterioration on U.S. 20 in Webster County, MLR-91-01, Iowa Department of Transportation, 1991
- ¹¹ Marks, V. and Dubberke, W., A Different Perspective for Investigation of PCC Pavement Deterioration, HR-1074, Iowa Department of Transportation, 1995
- ¹² Gress, D., Pooled-Fund Study for Premature Pavement Deterioration, HR-1063, 1996
- ¹³ Hanson, T. and Hart, J., Evaluation of PCC Specification Changes Impact on Durability: 1992 to 1997 Core Study, MLR-98-06, 1998
- ¹⁴ Gent, S., Evaluation of Various Cements in Combination with Ground Slag or Class F Fly Ash, MLR-94-06, 1994
- ¹⁵ Grove, J., Field Evaluation of Ash Grove Type IP Cement (I-29 Pottawattamie County), HR-2072, 1994
- ¹⁶ Leonard, C.E., Fly Ash in Portland Cement Concrete Pavement – Woodbury County, HR/TR-201, 1978
- ¹⁷ Cackler, T., Fly Ash Pavement Sections, HR-2012, 1980
- ¹⁸ Clauson, L.M., Slipform Paving as Developed and Pioneered in Iowa, presented at the Annual Highway Conference, Maine Section American Society of Civil Engineers, Bangor, Maine, November 2, 1961
- ¹⁹ Schlorholtz, S., Determine Initial Cause of Premature PCC Pavement Deterioration, HR/TR-406, 1997
- ²⁰ Tymkowicz, S. and Steffes, R., Vibration Study for Consolidation of Portland Cement Concrete, MLR-95-04, 1995
- ²¹ Cable, J., Evaluation of Paver Vibrator Frequency Monitoring and Concrete Consolidation, HR-1068, 1997
- ²² Marks, V., Variations of Tine Texturing of PCC Pavement, MLR-93-04, 1996
- ²³ Cable, J., Maturity and Pulse Velocity Measurements for PCC Traffic Opening Decisions, HR/TR-380, 1995
- ²⁴ Callahan, M. and Cabalka, C., Transverse Joint Sealing with Improved Sealants, HR/TR-276, 1985
- ²⁵ Steffes, R., Soff-Cut Centerline Joint and Potential Cracking Problem, HR-2078, 1995
- ²⁶ Steffes, R., Longitudinal Joint Forming in PCC Pavements, MLR-2000-03, 2000
- ²⁷ Less, R., Investigating Pavement Surface Variations, HR-152, 1974
- ²⁸ Schroeder, C., A Study of Faulted Pavements on PCC Pavements on Iowa Primary Highways, Iowa Department of Transportation, 1976
- ²⁹ Marks, V. and Betterton, R., Experimental Steel Fiber Reinforced Concrete Overlay, HR/TR-165, 1973
- ³⁰ Bergren, J., Bonded Thin-Lift, Nonreinforced PCC Resurfacing, HR-1009, 1977