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# Review of Cold In-Place Recycled Asphalt Concrete Projects

Sponsored by the
Iowa Department of Transportation
Project Development Division and the
Iowa Highway Research Board

February 1998
Iowa DOT Project HR-392

Iowa Department of Transportation

report FINAL

Department of
Civil and Construction Engineering
Iowa State University

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*"The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Division of the Iowa Department of Transportation, or of the Iowa Cold In-Place Recycling Research Committee."*

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# ABSTRACT

Highway Research Project HR-392 was undertaken to evaluate cold in-place asphalt recycled (CIR) projects in the State of Iowa. The research involved assessment of performance levels, investigation of factors that most influence pavement performance and economy, and development of guidelines for CIR project selection.

The performance was evaluated in two ways: Pavement Condition Indices (PCI, U.S. Corps of Engineers) were calculated and overall ratings were given on ride and appearance. A regression analysis was extrapolated to predict the future service life of CIR roads. The results were that CIR roads within the State of Iowa, with less than 2000 annual average daily traffic (AADT), have an average predicted service life of fifteen to twenty-six years.

Subgrade stability problems can prevent a CIR project from being successfully constructed. A series of Dynamic Cone Penetrometer (DCP) tests were conducted on a CIR project that experienced varying levels of subgrade failure during construction. Based on this case study, and supporting data, it was determined that the DCP test can be used to evaluate subgrades that have insufficient stability for recycling.

Overall, CIR roads in Iowa are performing well. It appears that the development of transverse cracking has been retarded and little rutting has occurred. Contracting agencies must pay special attention to the subgrade conditions during project selection. Because of its performance, CIR is a recommended method to be considered for rehabilitating aged low volume (< 2000 ADT) asphalt concrete roads in Iowa.

## INTRODUCTION

The most common method of rehabilitating asphalt roads prior to the 1980's was to provide a hot-mix asphalt (HMA) overlay. In some cases several overlays were placed to address problems with cracking and surface deterioration. This resulted in unnecessary structural thickness, reflective cracking, decreased overhead clearance, and decreased shoulder width. During the mid to late seventies, as a result of the shortage of asphalt cement caused by the oil embargo, the cost of asphalt cement increased. Because of this shortage, research focused on methods to recover asphalt from existing roads by recycling.

Cold in-place asphalt recycling (CIR) is one of the recycling methods that was developed. It involves milling and crushing the existing asphalt pavement, rejuvenating the existing asphalt cement, and finally placing and compacting the material to a specified thickness. This process is performed in-place, so there is little need to load and transport the material. Some of the first roads recycled by this process were (Scherocman, 1983):

1978 A county road in Livingston County, Michigan

1979 A county road in Scott County, Kansas

1979 US-395, California

1981 US-70, Arizona

Early projects demonstrated the effectiveness and benefits of CIR. One benefit of CIR is a decrease in the energy that is required to rehabilitate the road. The existing asphalt is used with the addition of an emulsion. There is no heating involved in the construction process. Furthermore, the process is performed "in-place" eliminating the added expenditure of transportation of materials. The result is a stable road for a total expenditure of forty to fifty percent less than that required by conventional rehabilitation methods (Asphalt Recycling and Reclaiming Association [ARRA], 1991).

Iowa experimented with recycling asphalt roads in 1981. The objective of that experiment was to evaluate CIR to predict its related construction and maintenance costs (Snyder and Callahan, 1988). Upon the completion of this experiment, oil prices stabilized and no further CIR was performed in Iowa until 1986 when Clinton County E-50 was recycled. Several other CIR projects followed.

Project selection is an important factor in assuring the success of a CIR project. The selection process should include an assessment of existing pavement conditions, sampling and testing of pavement, base, subbase, and subgrade materials, and a study of the pavement's construction and maintenance history and traffic (Hicks & Rogge, 1995). Determining the feasibility of CIR is essential to project selection.

The following is a list considerations for CIR project selection (Hicks & Rogge, 1995):

<u>CIR is not recommended in the following situations</u>

- Pavements with obvious subgrade problems
- Work areas that cannot accommodate traffic volume
- When asphalt strips from aggregate
- Mixes that exhibit rutting due to unstable, fat mixtures
- Cold and damp conditions, including heavily shaded areas
- When late fall or early winter treatment is required
- When the existing asphalt pavement is less than 1.5 inches thick
- When the intent is to widen roadway by reducing thickness and incorporating the shoulder rock.

<u>CIR is recommended in the following situations</u>

- Cracked and Broken Pavements
- Pavements raveled due to age
- Rough Pavements
- As leveling base for overlays
- ADT 5000 or less unless multilane
- Where selective rehabilitation is needed (e.g., in truck lane of 4-lane roadway)
- Native aggregate poor or in short supply

There have been cases, however, where projects have been designed and let as CIR projects, but construction could not be accomplished as planned due to inadequate subgrade support for the recycling equipment train. Though these cases are few, the failures were very costly, and have raised questions about the feasibility of the CIR process. There is currently no widely accepted practice for assessing subgrade stability prior to selection of projects for CIR. In May of 1997 a pavement in Pleasant Creek State Park experienced such a failure. An extensive study was performed to investigate the conditions that led to the failure.

The topics that will be covered in this study, pertaining to CIR roads in the State of Iowa are:

1. State of the Practice of CIR in Iowa.
2. Development of a method to evaluate the performance.
3. Evaluation of the current performance.
4. Prediction of the service life.
5. Investigation of the relationship between certain variables to the performance of CIR roads.
6. Development of a test to assess subgrade stability.
7. Development of guidelines to use in project selection.

The study started with the formation of a research steering committee. The committee included city engineers, county engineers, Iowa DOT engineers, and representatives form the Asphalt Paving Association of Iowa. The steering committee reviewed progress and made suggestions about the research approach. The members of the steering committee are listed in Appendix A.

Appendix B is a list of terms associated with pavement condition rating and indexing, asphalt recycling, and subgrade evaluation. This research is focused on CIR in Iowa. NCHRP Synthesis 160 (Epps, 1990) is an excellent reference regarding CIR on a national level.

## STATE OF THE PRACTICE

The CIR rehabilitation process involves three basic steps. The first step is breaking up and pulverizing the asphalt pavement in-place. Second, the reclaimed asphalt product (RAP) material is modified by the addition of an asphalt emulsion, water, and aggregates as required. Third, the RAP material is placed and compacted to a specified density. This process is carried out with little traffic disturbance during a short construction time. The construction equipment required to perform this process is readily available (Schoenberger, 1992).

Generally a pavement considered for CIR consists of five to ten inches of asphaltic concrete on granular base, or on subgrade soil. The old asphaltic concrete pavement may have many thermal and reflective cracks, and CIR is an excellent rehabilitation process for removing these distresses (Hicks & Rogge, 1995). The type and condition of the granular base (if any) varies from project to project. Typical CIR practice is to recycle 3 to 4 inches of the existing asphalt. In Iowa, an HMA overlay is usually placed on the recycled mat.

The following process is required to design and construct a CIR project:

*Selection* – Proper selection of pavements for recycling is critical to the success of projects. In most cases CIR cannot be used to remedy subgrade problems, because good subgrade conditions are necessary to support the CIR equipment and achieve proper compaction. Low volume roads with good subbase material and oxidized, raveled, and cracked pavements, are the best candidates for recycling. CIR has also been completed successfully on some high volume roads.

*Design* – There is no standard mix design procedure for CIR. An NCHRP Study (Puzinauskas, 1983) found that a precise laboratory design is not critical for achieving a successfully recycled project, but should serve a general guideline for an initial job-mix formula, with adjustments being made following an evaluation of mix quality, including such factors as workability, coating, plasticity, and ease of compaction.

The existing pavement structure is analyzed to determine the subgrade materials, thickness, gradation, and asphalt content. The depth of asphalt to be recycled must also be determined. Depth is normally determined by the amount of suitable material available. However, it is difficult to achieve compaction if recycling is more than four inches deep. Milling approximately seventy percent of the existing asphalt pavement is typical in industry. It is desirable to leave some existing asphalt on which to compact the recycled asphalt. However, the base of existing asphalt must not be too thick or the potential for reflective cracking may increase.

For CIR, the primary objective of the mix design is to produce a mixture comparable to one made from all new materials. Laboratory tests are used to establish the initial asphalt content with the intention of adjusting it, if necessary, after construction begins. To determine the optimum mix design, the designer must obtain samples of the existing pavement and analyzing the recycled asphalt pavement (RAP). Typical practice is to determine the asphalt content and the aggregate gradation of the RAP. Marshall stability (at 77 degrees F) and flow, percent moisture, soaked stability (at 77 degrees F), air voids, and the compacted density are also usually determined. The mix design determines the amount and type of asphalt to add. Depending on the testing of the RAP, Iowa specifications generally require asphalt emulsion to be injected at a rate of 0.3 gallons per square yard per compacted inch. This may be altered during construction by a decision of inspectors and contractors, depending on the look and feel of the CIR mix that is produced. The emulsion is capable of coating the individual RAP particles with a thin bituminous layer needed for recycling. CSS-1 is generally specified as the emulsion to be used during CIR. However, various transportation agencies in Iowa have experienced success using other high float and polymer modified emulsions (HF-300RP, HFE-150S, HFMS).

A study at Purdue University (Van Wijk, 1984) determined a mean value of 0.29 for the Structural Number (SN) coefficient of the CIR mix, ranging from 0.17 to 0.44. Other studies of performance conducted by Oregon State University and Oregon Department of Transportation (Hicks, Rogge, Sholz, & Allen, 1990) indicate that the CIR structural coefficient may be considered equivalent to that of a new HMA pavement. Although most agencies in Iowa do not follow a formal thickness design, the SN could be used in conjunction with a California Bearing Ratio (CBR) to determine pavement thickness.

*Cutting, screening, mixing, and paving* – This process is usually accomplished with a full CIR recycling train (Figures 1 & 2). The first piece of equipment is the milling machine, which rips and pulverizes the existing pavement. The RAP is then conveyed to a crushing and screening unit to ensure proper sizing. Oversize material is then recycled. Iowa Department of Transportation (IDOT, 1997) specifications require the final gradation of the CIR mix to have 98-100% passing the 1.25 inch sieve. The RAP is then carried to a pugmill where the asphalt emulsion is added and the materials are mixed and the mix is aerated. The RAP is usually placed in a windrow, picked up by an elevator, and placed in the hopper of a paving machine. Alternatively it may be placed directly into as asphalt paving machine and layed back onto the roadway. For the first CIR projects in Iowa, a mobile rotary milling machine was used. A spray bar inside the milling compartment was used to add the asphalt emulsion. Further mixing, aeration, and shaping were then accomplished using a motor grader.

*Compaction* – The recycled asphalt is initially compacted using pneumatic rollers. Sheepsfoot or vibratory rollers have also been used. Steel wheeled rollers are used for final compaction. Iowa DOT (Iowa DOT, 1997) specifications for secondary roads require the mat to be compacted to 92% of the laboratory density based on dry weight of compacted material. Primary roads require 94% of the laboratory density.

*Surface Course* – After the recycled asphalt has cured for several days, a surface course of hot mix asphaltic concrete (HMA) or a chip seal is placed on the CIR mat. Iowa DOT (Iowa DOT, 1997) specifications require that the recycled mat be allowed to cure for at least seven days. Traffic is generally allowed to travel on the pavement during this time. In Iowa HMA has usually been used as a surface course. A two or three inch thickness is typical. A chip seal surface course has been used for short sections of lightly traveled roads in Tama County and in many other states.

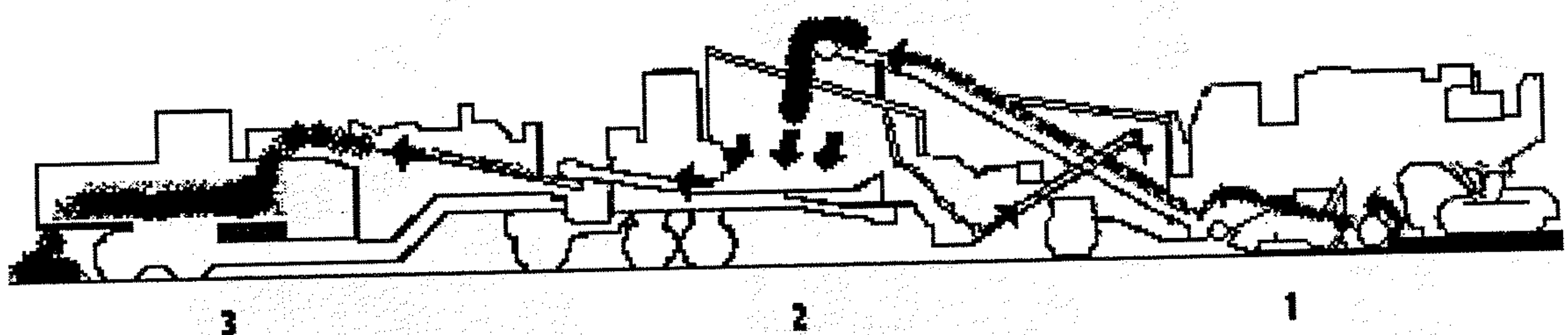
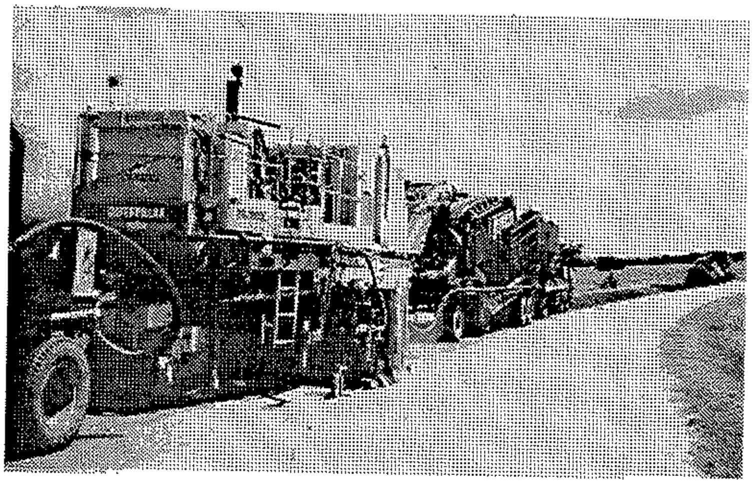
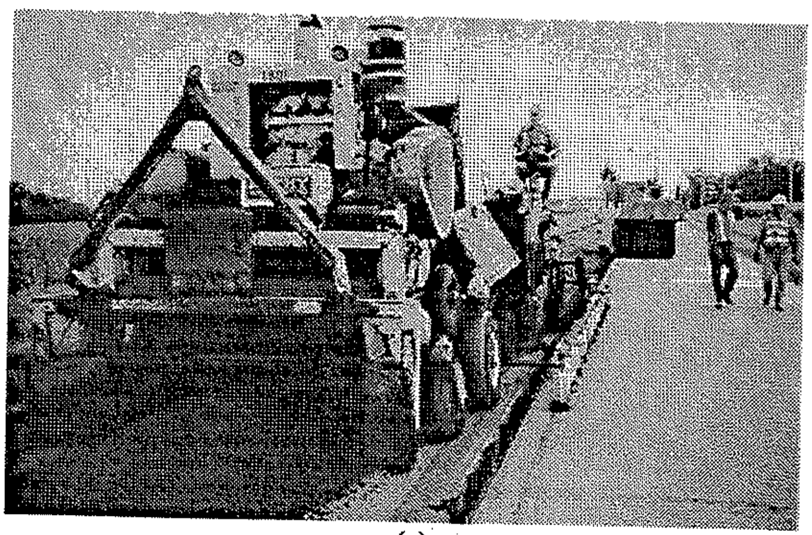



**Figure 1: Typical CIR Train (moving left to right)**
**(1)milling machine (2)screening unit (3)pugmill and windrow**



(a)

(b)



(c)

**Figure 2: Operating CIR Train (Carroll County 1996 - moving right to left)**
**(a) milling machine (b) screening unit and pugmill (c) laydown machine**

*Reclamation*

One alternative to a using a full recycling train for recycling is reclamation. Cold in-place reclamation is a road construction technique where the existing pavement, base and/or subbase materials, is pulverized in-place and mixed cold with asphalt emulsion or other base stabilizing additives (Caterpillar Paving, 1993). The difference between CIR and cold in-place reclamation is the depth of the process. CIR does not incorporate base material into the recycling while reclamation does.

*Urban Construction*

Urban pavements are a challenge for CIR. Manholes and existing curbs are difficult to maneuver around. It is usually not possible to use traditional recycling trains. Urban pavements can be recycled if certain measures are taken. The manhole covers can be removed before the milling and covered with a steel plate. So, the machine can then pass over the manhole. After the overlay is placed, the hole must be relocated and replaced. It can then be patched with hot mix asphalt by hand.

In the case of curbs and manholes, a different type of equipment may be selected. It has been done using a reclaiming machine to recycle the pavement and produce a base material (Figure 3).

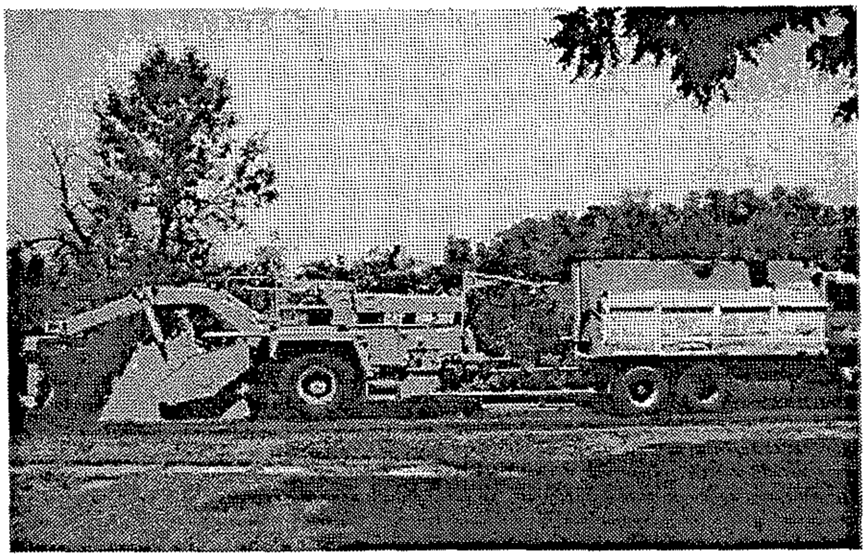


**Figure 3: Reclamation Machine Used on Union County H17 (1997)**

*Widening*

CIR construction has been used to widen roads in Tama (Gumbert and Harris 1993) and Cerro Gordo Counties. Somewhat different processes were used in each county.

A Tama County road E66 between the Benton County line and US 30 was widened by three feet per lane in 1990. This road is part of old US 30. The pavement structure is PCC concrete overlaid by at least seven inches of ACC. The process required several steps. First a three-foot wide trench was excavated nine inches deep at the edge of the road. Then a recycling train milled three inches of ACC from the road and left the recycled material in a windrow. Motor graders bladed the windrow into the trench in two lifts. After each lift, the recycled material was compacted with rear dual wheels of a loaded tandem axle dump truck. After compaction, the recycled material was struck off with a motor grader blade. At this point the previously existing road had a milled surface and the widened shoulders were flush with the milled surface. Next the road was chip sealed and allowed to set over the winter. During the next construction season, the remaining asphalt on the previously existing road was recycled to a depth of four inches. The widened shoulders were recycled concurrently. The recycled material was placed with a paving machine and compacted. Then a three inch HMA (hot mix asphalt concrete) overlay was placed. When the performance survey for E66 was conducted in 1996, it had few cracks and provided a smooth ride. Longitudinal cracks were not visible at the widening joint.

Tama County E49 between Tama and Montour was widened in 1997 using the same methods. It is scheduled for recycling and overlay during the 1998 construction season.

Cerro Gordo County's South Shore Drive (south shore of Clear Lake) was recycled and widened in 1990. The widening process started by excavating a four-foot wide section of the shoulders to a depth of three inches. Then the twelve-foot wide driving lanes were milled to a depth of four inches and the millings were recycled. Next the recycled material was placed (using a paving machine) to a depth of three inches across the width of the driving lanes and the new shoulders. Finally the driving lanes and shoulders were overlayed with two inches of HMA. When the performance survey was conducted 1996, the shoulders were performing well.

## PERFORMANCE OF CIR ROADS

### CIR Roads

The first task of this research project was to find when and where CIR roads had been constructed in Iowa. This was accomplished by reviewing a list of CIR construction projects obtained from the Iowa DOT Office of Contracts and by surveying counties and cities. As of the 1996 construction season, 97 CIR projects had been completed throughout Iowa (Figure 4).

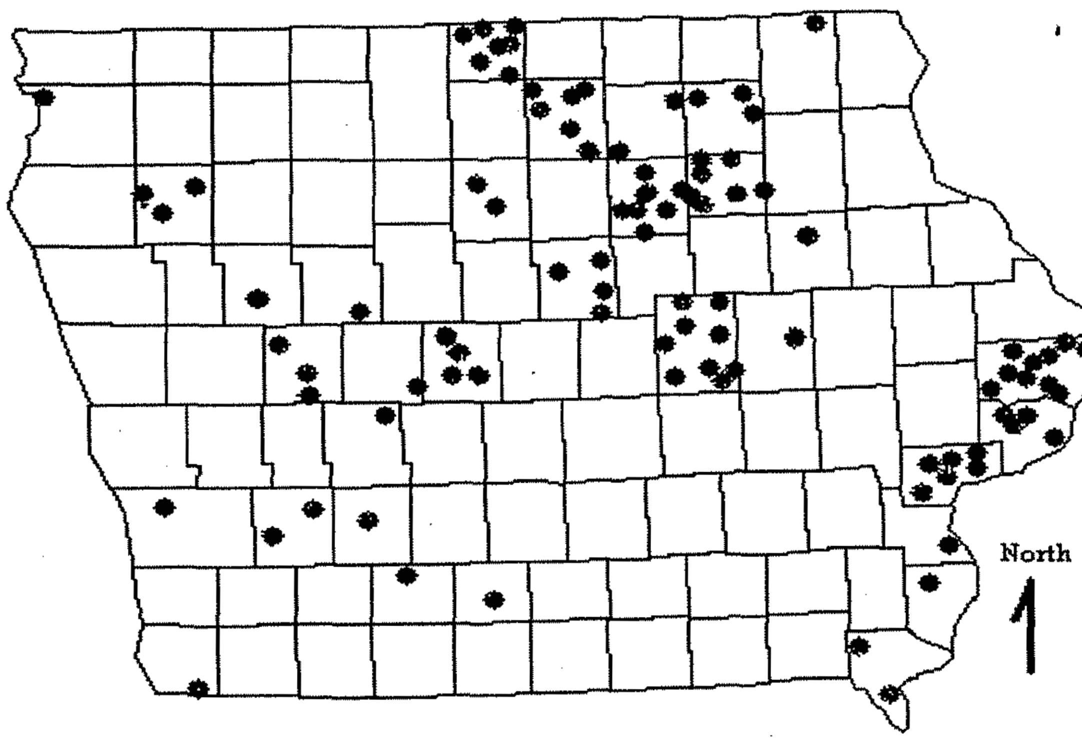



**Figure 4: CIR distribution 1996**

After locating all of the CIR roads in Iowa, eighteen roads were selected for detailed analysis. During the selection process, researchers were careful to obtain roads with a variety of average annual daily traffic (AADT) counts, ages, geographical locations, and construction contractors. The AADT ranged from 300 to 2000. This is considered to be in the range of *low volume* traffic. The percent of trucks varied from five to eighteen percent. Truck percentages are estimates because county engineers do not count the number of trucks on county roads. A variety of subgrade conditions were obtained by selecting roads from portions of the state that experienced a variety of geomorphological processes. Geomorphology refers to the process that formed the landscape. Contractors that have constructed CIR roads in Iowa use *similar* processes, and follow the same specifications. Due to the similarities, it is unlikely that the contractors had much influence on pavement performance.

Using these criteria, personal conversation with engineers, and the guidance of the steering committee, eighteen roads were selected for in-depth analysis. (Table 1 and Figure 5). The sample included 15.5% of the ninety-seven county roads and one third of the nine state highways.

**Table 1: CIR roads surveyed**

| COUNTY | ROAD | YEAR CONSTRUCTED | YEAR SURVEYED |
|---|---|---|---|
| Boone | 198th Street | 1988 | 1996 |
| Boone | E-52 | 1991 | 1996 |
| Butler | T-16 | 1993 | 1996 |
| Calhoun | IA-175 | 1994 | 1997 |
| Cerro Gordo | B-43 | 1989 | 1996 |
| Cerro Gordo | South Shore Line | 1990 | 1996 |
| Clinton | E-50 | 1986 | 1996 |
| Clinton | Z-30 | 1989 | 1996 |
| Greene | IA-144 | 1990 | 1997 |
| Guthrie | IA-4 | 1995 | 1997 |
| Hardin | D-35 | 1992 | 1996 |
| Muscatine | Y-14 | 1987 | 1996 |
| Muscatine | G-28 | 1991 | 1996 |
| Muscatine | F-70 | 1993 | 1996 |
| Tama | E-66 | 1990 | 1996 |
| Tama | V-18 | 1991 | 1996 |
| Winnebago | R-34 | 1990 | 1996 |
| Winnebago | R-60 | 1990 | 1996 |

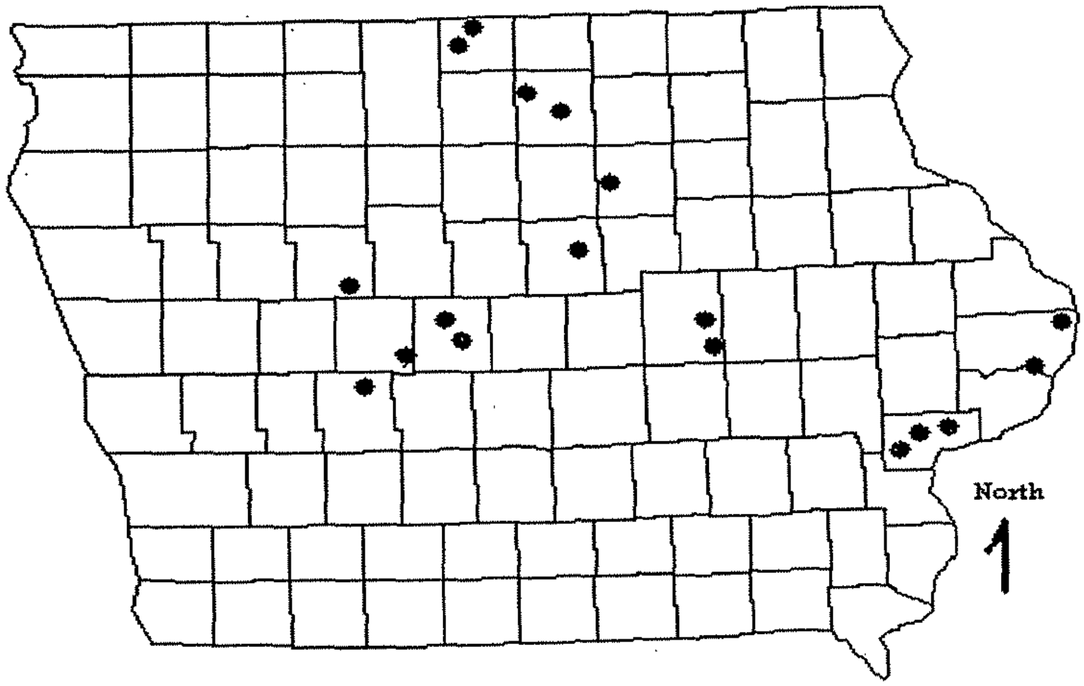



**Figure 5: CIR roads performance surveyed 1996 and 1997**

Road performance is evaluated both quantitatively and qualitatively. For the quantitative evaluation, roads are surveyed for severity and type of distresses. By analyzing quantitative evaluations at the network level, predictions may be made concerning the future performance of the road network for various maintenance and rehabilitation treatments. Economic analysis may be used to choose the best plan of action.

Public perception of road condition is based on qualitative assessments that are made as users drive over the roads. These perceptions are communicated to transportation officials who also drive over the roads and make qualitative assessments before they make maintenance and rehabilitation decisions. Thus it is reasonable to include both a quantitative and qualitative component to the performance evaluation process for CIR roads.

The quantitative assessment procedure for this project was developed using the method outlined by the US Army Corps of Engineers (Shahin and Walther,1990). This evaluation technique requires an in-depth survey of the pavement surface. Surface distresses are recorded and classified by severity. The severity level is determined by guidelines that included in the USACE manual. Then numerical deductions are assigned for each severity and type of distress. These deductions are combined mathematically to provide a pavement condition index (PCI). The PCI can range between zero and one hundred with the higher numbers indicating a pavement that is in better condition.

The qualitative assessment procedure was developed using guidelines from the American Association of State Highway and Transportation Officials (AASHTO, 1993). The qualitative evaluation provided separate ratings for appearance and ride (Appendix C). The two evaluations were averaged to produce the PSI rating.

Researchers started the evaluation process by driving over the entire road and making the qualitative evaluation with the aid of a rating form. After researchers had an overview of the road, a representative 0.25 mile section was selected for the quantitative evaluation. During the survey, this section was covered on foot and a crack map was made. Upon completion of the quantitative evaluation, a survey was conducted to further establish the frequency of transverse cracks. The length of this survey varied from 0.5 to 3 miles, depending on the frequency and consistency of the transverse cracks.

The results of the evaluations are provided in Table 2. The roads are sorted in order of increasing age. The PSIs ranged from 90 to 51 while the PCIs ranged from 100 to 52. The averages of the PCI and PSI ranged from 95 to 56.4. Clinton County E-50 was the first road that was recycled in Iowa. It had a PSI of 51, a PCI of 81 and an average of 66.2. A rating of 25 was chosen to be the point when a road should be rehabilitated. This corresponds to the rating where the USACE pavement condition scale changes from poor to very poor. This indicates that none of the roads that have been recycled thus far in Iowa are in need of rehabilitation.

With regard to rutting, only one third of the roads had deductions for rutting, as shown in Table 2. This indicates that rut depths were less than 0.25 inches for these roads. Of the roads that did have deductions, none exceeded a deduct value of 17. Explanations are available for the two roads that had rut deductions of 17. In Boone County, 198th street was originally a cold mix pavement laid on earth subgrade. In locations where rutting occurred, the county engineer recalls the occurrence of equipment breakdowns that resulted in extra water being introduced in the RAP. In Greene County, IA 144 was constructed during a cold, rainy period that was not favorable to CIR construction. Note that these two roads are the only roads that received deductions for alligator cracking. With these exceptions, rutting has not been a performance issue in Iowa.

The highest deduction for transverse cracking was 15. More than a third of the roads received no deduction for transverse cracking. The number of transverse cracks per kilometer ranged from zero to 202. Figure 6 shows the frequency of transverse cracks. Only two of the roads exceeded 120 cracks per mile and more than two thirds had fewer than 58 cracks per mile. Records were not kept regarding the original number of cracks per mile. However, it is the writers' experience that before recycling, most roads in Iowa have transverse cracks every 20 to 30 ft. This is equivalent to 175 to 260 cracks per mile. This would indicate that CIR has been effective in mitigating transverse cracks.

Muscatine County Y-14 has deductions for raveling and slipping. These deductions were the result of defects in the hot mix overlay and have nothing to do with CIR performance.

How long will CIR roads last in Iowa? This is a difficult prediction to make in the absence of any actual experience. However, regression analysis was used to estimate the service life. First the analysis was performed on the age vs. PCI and age vs. PSI separately. Linear regression lines were extrapolated into the future and 95% confidence intervals were determined. The confidence interval indicates that if the relationship actually is linear, then with a confidence of 95% the mean response will fall within the interval. Thus the assumption is made that the roads will be maintained in the future so that a linear relationship between age and pavement condition will continue. If the roads are not maintained, sudden deterioration will occur at some point and the relationship between age and pavement condition will not be linear. Similarly, by applying very vigorous maintenance it may be possible to slow the deterioration of pavement condition with age, again creating a non-linear relationship. In general it seems reasonable to expect that the relationship will be linear. It was also assumed that the roads reach the end of their service life, that is, they must be rehabilitated when the pavement performance index reaches 25.

The regression equations, $R^2$, and minimum and maximum average expected service life are shown in Table 3. The $R^2$ indicates the percentage of the variation of the data that is explained by the regression equation. A graphical representation of the regression analysis is presented in Figure 7. Considering the PSI only, the mean predicted service life is 14 to 19 years. Considering the PCI only, the mean predicted service life is 14 to 38 years. Considering the average of the indices, the mean predicted service life is 15 to 26 years. Since rehabilitation decisions are often a combination of a qualitative and quantitative input, the writers have chosen the average of the PSI and PCI as the best prediction. Note that the predicted lifetime will vary depending on the terminal index chosen for rehabilitation.

**Table 2: Performance Data from CIR roads surveyed 1996 and 1997**

| County | Road | AADT | Yr. Const. | Yr. Srvyd. | Age | Cracking Algtr. | Block | Edge | Long | Trans | Raveling | Rutting | Slippage | Shoving | PSI | PCI | (PSI+PCI) /2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Guthrie | IA-4 | 820 | 1995 | 1997 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 90 | 100 | 95 |
| Butler | T-16 | 470 | 1993 | 1996 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 81 | 100 | 90.7 |
| Calhoun | IA-175 | 1920 | 1994 | 1997 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 81 | 100 | 90.7 |
| Muscatine | F-70 | 950 | 1993 | 1996 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 | 100 | 90.8 |
| Hardin | D-35 | 665 | 1992 | 1996 | 4 | 0 | 8 | 0 | 0 | 8 | 0 | 3 | 0 | 0 | 65 | 85 | 75 |
| Boone | E-52 | 290 | 1991 | 1996 | 5 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 73 | 95 | 83.8 |
| Muscatine | G-28 | 940 | 1991 | 1996 | 5 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 73 | 98 | 85.3 |
| Tama | V-18 | 550 | 1991 | 1996 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 100 | 85 |
| Cerro Gordo | S.S. | 600 | 1990 | 1996 | 6 | 0 | 0 | 0 | 4 | 14 | 0 | 1 | 0 | 0 | 61 | 81 | 71.2 |
| Tama | E-66 | 1080 | 1990 | 1996 | 6 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 61 | 94 | 77.7 |
| Winnebago | R-34 | 620 | 1990 | 1996 | 6 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 63 | 90 | 76.3 |
| Winnebago | R-60 | 340 | 1990 | 1996 | 6 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63 | 72 | 67.3 |
| Cerro Gordo | B-43 | 570 | 1989 | 1996 | 7 | 0 | 12 | 0 | 11 | 3 | 0 | 8 | 0 | 14 | 68 | 77 | 72.3 |
| Clinton | Z-30 | 850 | 1989 | 1996 | 7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 6 | 0 | 64 | 93 | 78.4 |
| Greene | IA-144 | 1110 | 1990 | 1997 | 7 | 33 | 1 | 0 | 4 | 7 | 0 | 17 | 0 | 0 | 58 | 60 | 59 |
| Boone | 198th | 300 | 1988 | 1996 | 8 | 18 | 0 | 0 | 3 | 0 | 0 | 17 | 0 | 0 | 59 | 71 | 64.9 |
| Muscatine | Y-14 | 990 | 1987 | 1996 | 9 | 0 | 0 | 0 | 5 | 7 | 16 | 9 | 54 | 0 | 61 | 52 | 56.4 |
| Clinton | E-50 | 520 | 1986 | 1996 | 10 | 0 | 0 | 0 | 1 | 15 | 0 | 10 | 0 | 0 | 51 | 81 | 66.2 |

**Table 3: Indices evaluation**

| Index | $R^2$ | Equation | Minimum average life | Maximum average life |
|---|---|---|---|---|
| PSI | 78.2% | =91.7-4.19**Age* | 14 | 19 |
| PCI | 49.4% | =114.97-4.84**Age* | 14 | 38 |
| (PSI+PCI)/2 | 72.9% | =101-4.56**Age* | 15 | 26 |

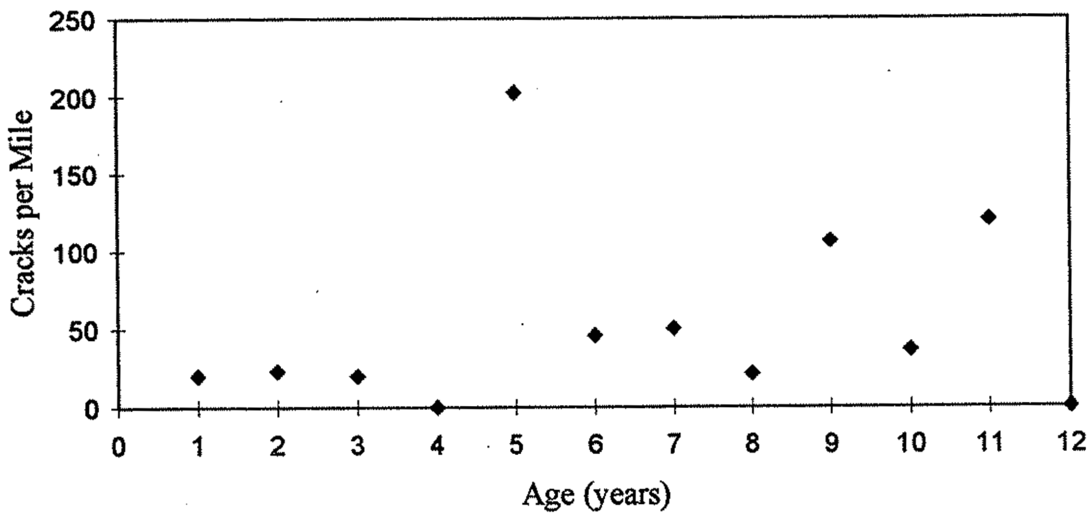



**Figure 6: Frequency of transverse cracking**

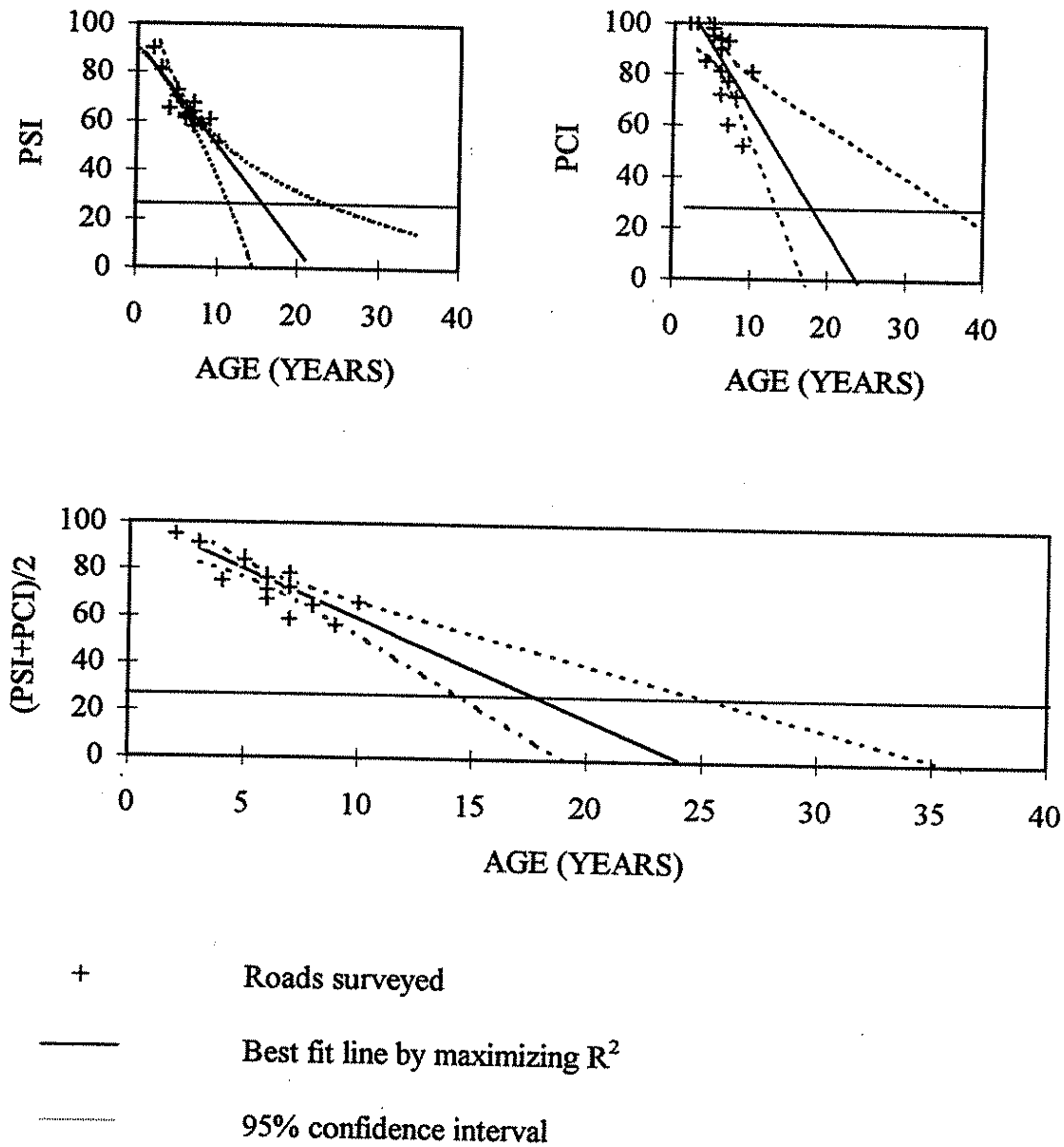



**Figure 7:** **Life expectancy**

It was desired to determine the origin of the cracks in CIR pavements. It is possible that the cracks are reflective (originating in the asphalt that was not recycled) or thermal cracks (originating in the overlay due to expansion and contraction of that portion of the pavement).

Cracks in pavements that were constructed during the 1995 and 1996 construction seasons were cored. These projects included M68 in Carroll County and T25 in Butler County (Tables 4 and 5). M68 consisted of 2 inch HMA overlay, 4 inches of RAP, and1 inch of unrecycled pavement on 6 inches of base. T25 consisted of 3 inch HMA overlay, 3 inches of RAP, and 2 inches of unrecycled pavement on 2 inches of base. Some cracks in M68 went completely through the recycled pavement and the hot mix surface (Figure 8). These were likely to be reflective cracks that initiated in the unrecycled asphalt. Other cracks started in the hot mix surface and ended in the CIR (Figure 9). They are likely to be thermal cracks. The investigation of Butler County T25 showed similar results. Overall, about half of the cracks were reflective cracks and half of the cracks were thermal cracks.

**Table 4. Carroll County M68 Crack Investigation**

| Location | Type of Crack |
|---|---|
| **A** | Thermal |
| **B** | Reflective |
| **C** | Reflective |
| **D** | Thermal |
| **E** | Thermal |

**Table 5. Butler County T25 Crack Investigation**

| Location | Type of Crack |
|---|---|
| **A** | Reflective |
| **B** | Reflective |
| **C** | Thermal |
| **D** | Thermal |
| **E** | Reflective |

Researchers reviewed the files of each of these construction projects and recorded the design and construction characteristics for each highway (Appendix C). Researchers visually inspected this data in an attempt to find correlations between performance and design variables, and between performance and construction variables. The roads were placed in four performance categories:

A. Performance exceeds 95% confidence interval (Figure 7).

B. Performance above the regression line but below the upper 95% confidence limit.

C. Performance below the regression line, but above the lower 95% confidence limit.

D. Performance below the 95% confidence limit.

Researchers considered HMA overlay and CIR characteristics, subgrade soil, depth of frost penetration, contractor, and whether the road was recycled early or late in the season. Visual review of the data revealed no probable correlation.

**Figure 8: Reflective Crack from Carroll M-68**

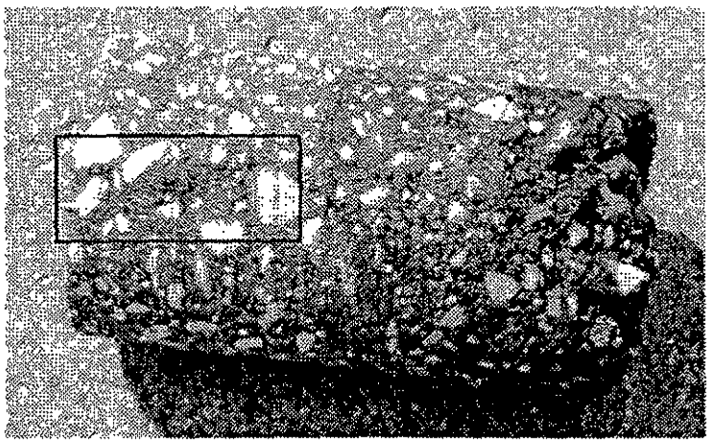
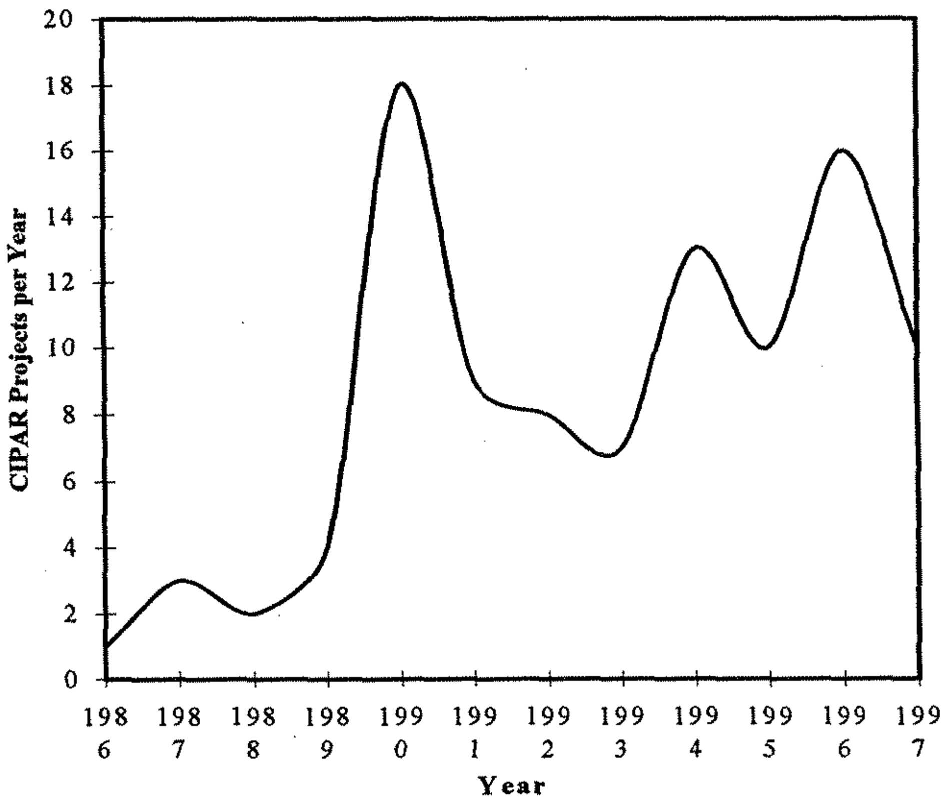


**Figure 9: Thermal Crack from Carroll M-68**

## Historical Costs

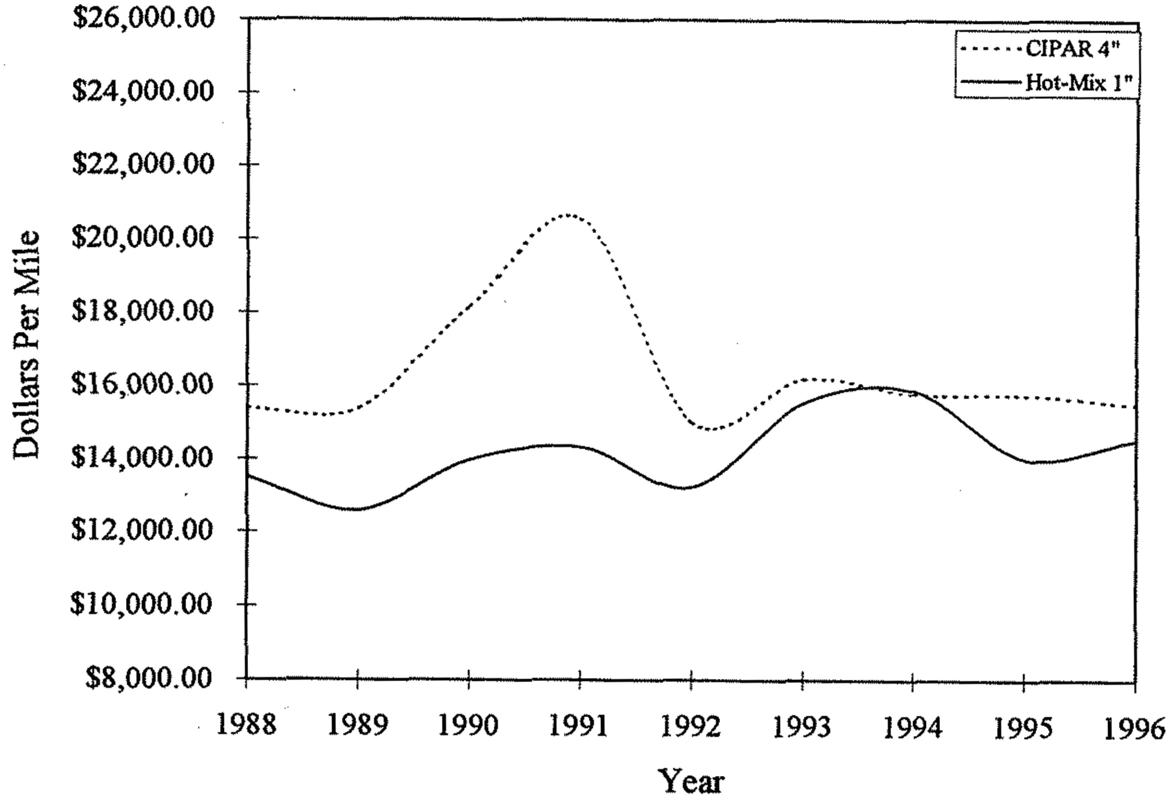
An investigation was conducted regarding the historical costs of CIR Construction in Iowa. Cost data were obtained from Iowa DOT bid tabulations. The number of projects per year has fluctuated (Figure10). Between 1986 and 1989, there were no more than four projects per year. Nineteen ninety had the most activity with 18 projects. Since then, there have been between seven (in 1993) and sixteen (in 1996) projects per year.

**Figure 10. Number of CIR Projects per Year, 1986 - 1997**



The average historical costs per road mile (two lane miles) for four inches of CIR and one inch of HMA are shown in Figure 11. The cost of CIR has ranged from \$14,000 to \$21,000 per road mile. The high cost occurred the season after the year of the greatest number of CIR projects. Recently the average cost of four inches of CIR and the cost of one inch of HMA has been \$13,000 to \$16,000.

**Figure 11. Cost Comparison of CIR and HMA Overlay**



## SUBGRADE STABILITY

### Background

The importance of proper project selection with regard to subgrade stability has been shown in Iowa. There have been two primary problems associated with CIR on unstable subgrade. The most difficult problem occurs when the equipment "breaks through" the remaining asphaltic cement concrete and gets stuck in the subgrade soil. The other problem is the recycled mat may ravel while curing. This is the result of inadequate compaction of the CIR mat overlaying a soft subgrade.

There have been at least three projects in the State of Iowa where recycling equipment "broke through" the remaining unrecycled asphalt due to a lack of subgrade stability: Iowa Highway 92 in Adair County (1994), County Highway G40 in Louisa County (1996), and the roadway in Pleasant Creek State Park in Linn County (1997). Subgrade conditions on these projects were so consistently inadequate that the contracting authorities abandoned the CIR process during construction. (Table 6)

The researchers have received reports of minor subgrade stability problems on several projects. Short sections of the recycled mat, 5 to 50 feet long, raveled because proper compaction could not be achieved on the soft subgrade. Removing the CIR material, digging out the soft subgrade materials, replacing them with imported aggregate material, then using HMA to replace the recycled mat repairs these areas. In one case (Tama County V18, 1991) the raveled CIR material was left in place and the subgrade underneath was allowed to dry. The area was then covered with slurry seal and later paved with hot-mix asphaltic concrete. To date this area has performed as well as other parts of the projects.

**Table 6: CIR projects where equipment "broke through"**

| Road | Date Recycled | Date Investigated |
|---|---|---|
| Louisa County G40 | 1995 | Aug. 1996, June 1997 |
| Pleasant Creek State Park | May 1997 | May 1997 |
| Iowa 92 - Adair County | 1994 | May 1997 |

When equipment "breaks through," it is usually due to a combination of factors. First, the equipment is heavy and applies a large vertical load to the pavement. Second, after the milling head passes, the rear driving track of the milling machine is only supported by the remaining asphaltic concrete and the subgrade soil. This track must supply traction not only to move the milling machine (Figure 12), but also to push and pull other parts of the recycling train. The vertical load of the equipment, combined with the shear forces caused by the tractive effort can shear and puncture the remaining asphaltic concrete into the subgrade soils if they are soft and weak.

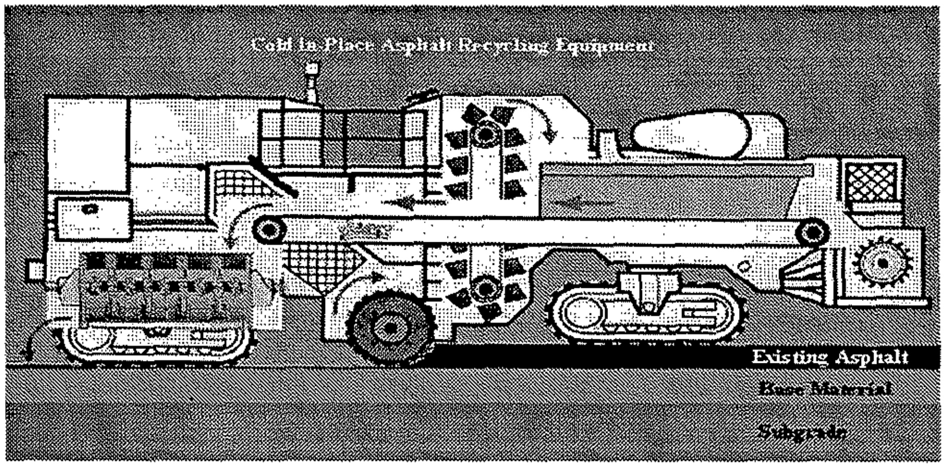



**Figure 12: Milling Machine used in CIR Train (Roadtec, Inc.)**

The objective of this research was to develop a test that contracting agencies can use to determine the level of subgrade stability necessary so project selection decisions can be made regarding the feasibility of CIR. This test should be repeated throughout the proposed project area so planners can determine whether or not CIR is a feasible option for pavement rehabilitation. It was also be desirable to develop a test that allows transportation agencies to confirm data regarding the thickness of existing asphaltic concrete and granular base material (if any).

## Test Development

A Soil Cone Penetrometer (Figure 13) was the first device used in an attempt to measure subgrade stability. A penetrometer is a device consisting a shaft with a cone-shaped tip on an end that is pushed into the soil, and a large head to apply pressure on the other. There is a proving ring near the head of the instrument that is used to determine the applied pressure. A dial gauge inside the proving ring measures the pressure in pounds per square inch.

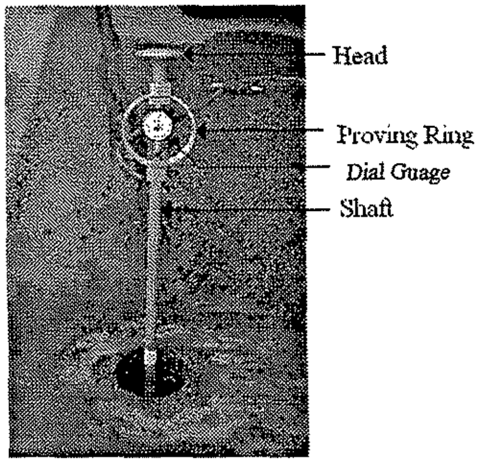



**Figure 13. Soil Cone Penetrometer**

The procedure involved using a four inch core drill to remove the asphaltic concrete and aggregate base. After the core was removed, the penetrometer was pushed into the subbase or subgrade to determine the strength of the underlying soil. The penetrometer is pushed in to the subgrade at a constant rate, and the cone resistance to penetration is measured. This test gives an assessment of subgrade stability, but the procedure is time consuming and has a potential for inaccuracy. It is difficult to achieve a constant rate of penetration, and therefore difficult to obtain exact measurements. Also, as the core drill cut through the asphalt, it introduced water into the soil, which may have reduced the stability.

Researchers chose a Dynamic Cone Penetrometer (DCP) to measure subgrade stability. The DCP (Figure 14) is a standard device used to measure the in-place stability of a soil (Sanglerat, 1992). The DCP is a 1.375 inch steel shaft with a 45 degree cone at its tip. The device uses a 15 pound weight that falls 20 inches to strike an anvil on the shaft and drives the cone into the soil. The penetration into the soil can be measured for each blow, and a measure of subgrade stability determined. The test requires a hole through the existing asphalt and base materials to the subgrade of the pavement. A hammer drill with a 2 inch masonry bit was used for this purpose.

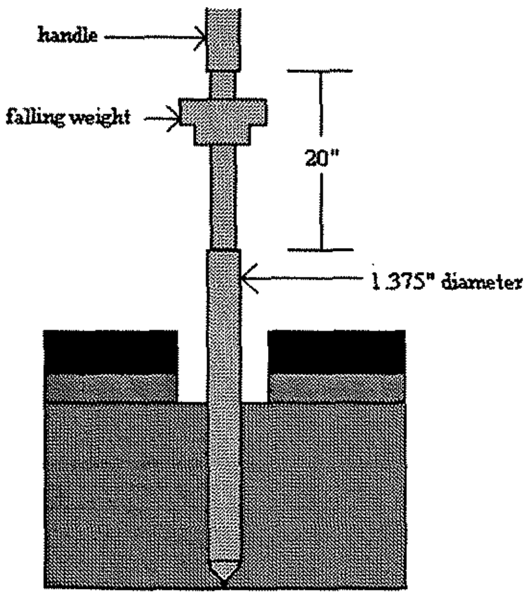



**Figure 14: Dynamic Cone Penetrometer**

**Pleasant Creek State Park**

In May of 1997, CIR was performed on 1.8 miles of a pavement rehabilitation project in Pleasant Creek State Park in Linn County, Iowa. The initial plan was to recycle 4 miles of pavement. An overlay was to be placed on the entire recycled mat.

The pavement consisted of six inches of hot mix asphaltic concrete placed directly on the subgrade soil. The pavement had severe transverse cracks spaced from one hundred to two hundred feet apart as shown in Figure 15. CIR was the process chosen to eliminate these transverse cracks. As the project progressed, CIR was completed with varying degrees of success. The milling machine began the project by milling four inches of the existing pavement. After difficulty was experienced with subgrade stability, the milling depth was reduced to three inches. Subgrade instability continued to be a problem. Figure 16(a) shows an area of the project that was successfully recycled. Figure 17(a) shows an area of the project that experienced moderate distresses. Figure 18(a) shows an area of the project that experienced severe distresses. In areas such as these, the equipment punctured through the two inches of underlying asphalt and became stuck in the subgrade. After the recycling train "broke through" in two different locations, the contracting authority decided to stop recycling, and choose an alternate rehabilitation method to complete the project. This included removing the soft subgrade on portions of the project that were raveling and the spots where the equipment "broke through". The subgrade was replaced with new granular base material. There was an additional mile of the project that was not recycled at all and where the cracks were routed and sealed. Then the entire pavement was overlaid with HMA.

Two days after CIR was abandoned on the project, DCP tests were conducted in thirty-one different locations exhibiting varying levels of distress of the recycled mat. (Test locations are shown in Appendix E.) Subgrade conditions during the testing were nearly the same as they were when the problems occurred. The test locations were distributed throughout the project and included areas where failure occurred, as well as areas where CIR was successfully performed. The purpose of the testing was to investigate the feasibility of using the DCP test to establish subgrade stability levels that could be used to predict whether or not the recycling equipment could operate without breaking through.

After the DCP blow count measurements were taken, a subgrade soil sample was taken from the hole. The sample was then tested for moisture content, to investigate possible relationships between subgrade stability and moisture content. The subgrade soil contained various types of clayey soils derived from glacial till. Topsoil was also present in some samples.

**Figure 15: Condition of the Pleasant Creek State Park road before recycling**

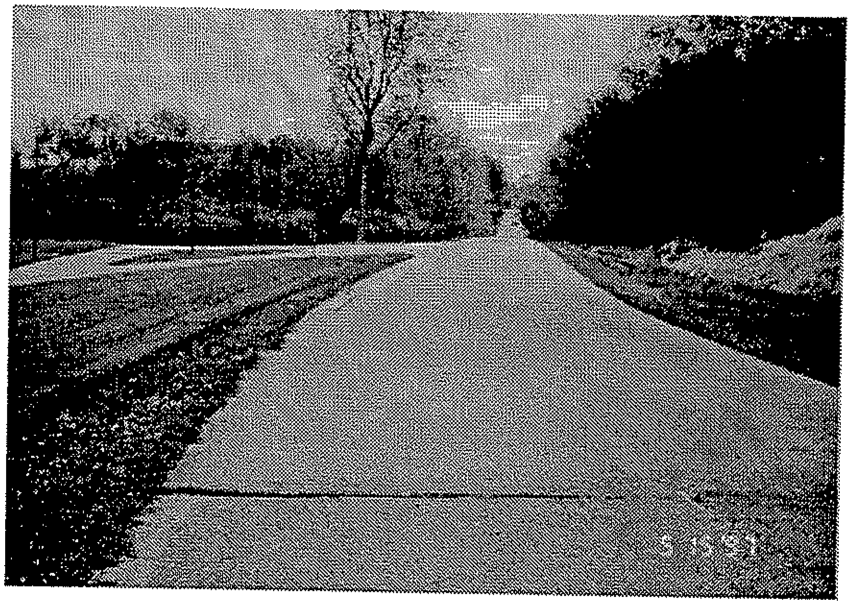
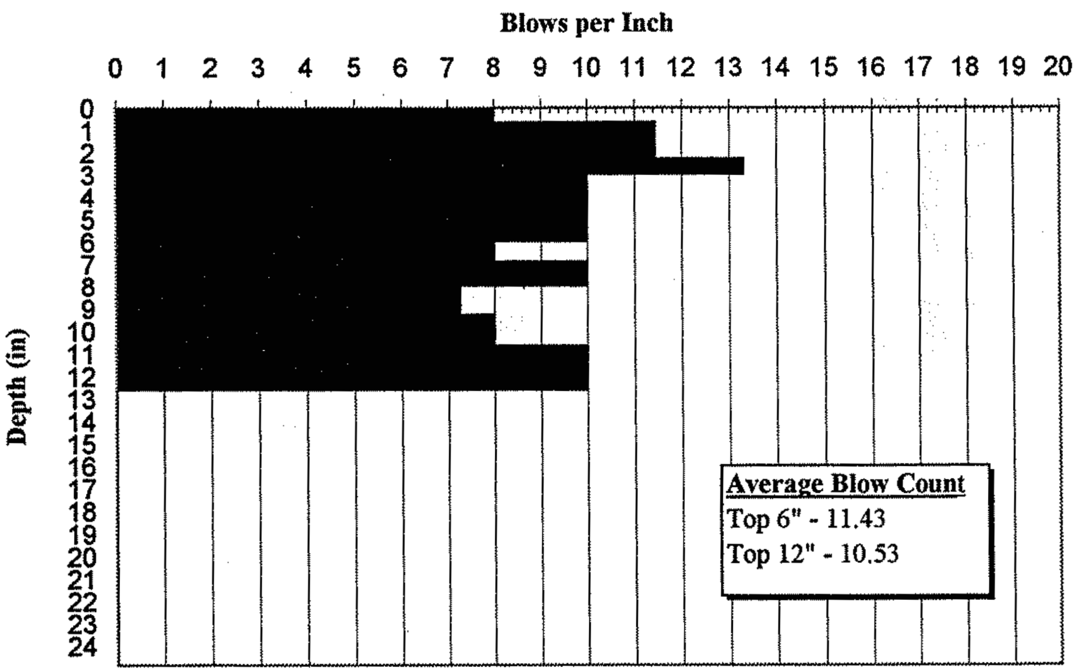


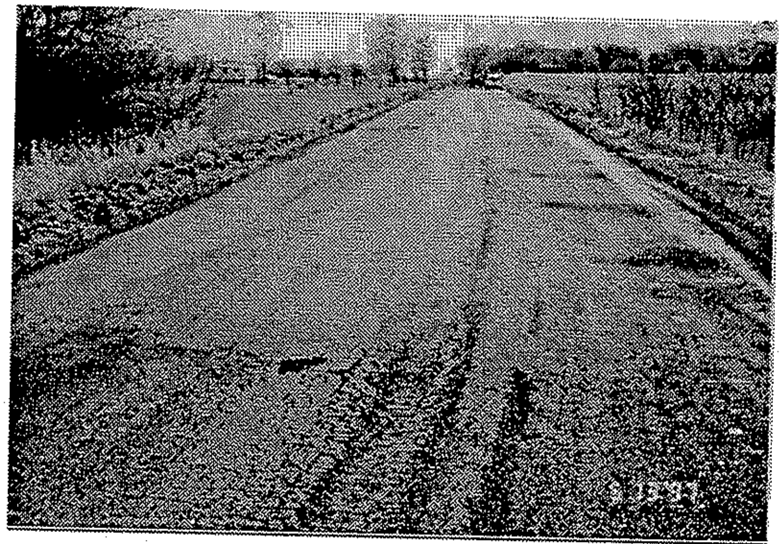
**Figure 16:** ***(a)*** **Recycled Mat with No Distress. Pleasant Creek State Park Road**
***(b)*** **Typical DCP Profile of Subgrade where CIR Mat was in Good Condition**

*(a)*

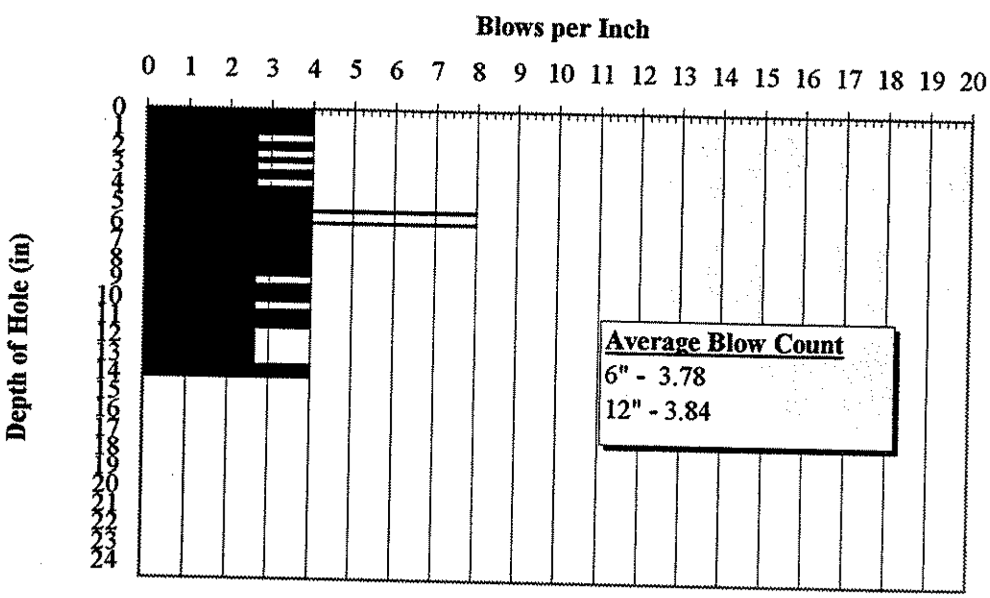



*(b)*

**Figure 17:** ***(a)*** **Recycled Mat with Moderate Distresses. Pleasant Creek State Park Road**
***(b)*** **Typical DCP Profile of Subgrade where CIR Mat had Moderate Distresses**



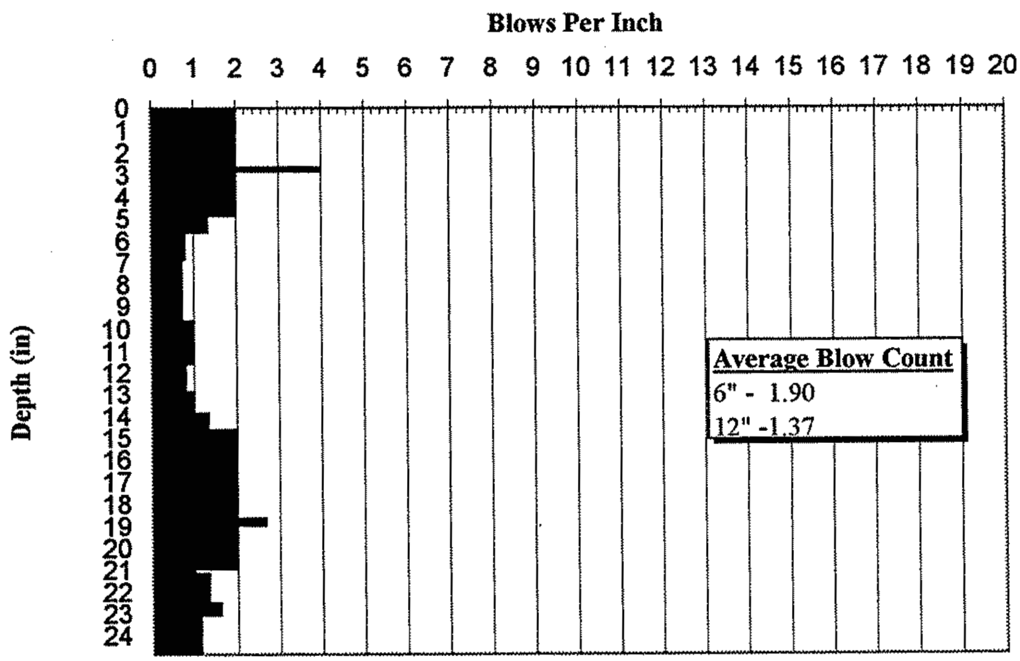
*(a)*




*(b)*

**Figure 18:** ***(a)*** **Recycled Mat with Severe Distresses**
**Pleasant Creek State Park Road**
***(b)*** **Typical DCP Profile of Subgrade with Recycled Mat Heavily Distressed**

*(a)*




*(b)*

**Results**

The results were analyzed by comparing the DCP blow counts among the various distress categories. At each test location, the amount, type, and severity of distress was recorded. Then the locations were categorized as having high, moderate, or low levels of distress. [See figures 16(a), 17(a), and 18(a)]. Figure 16(b) shows a typical blow count profile taken from a location with no distress. Figure 17(b) shows a typical blow count profile from a location with moderate distress. Figure 18(b) shows a typical blow count profile taken from a location with severe distress, where the equipment broke through. During the DCP test, the amount of penetration was measured for each blow. These data were then converted to the number of blows for one inch of penetration. Table 7 shows the DCP blow count data recorded for each distress category. Figure 19 shows the average DCP blow count per inch of penetration for the top 12 inches of the subgrade each distress category. In severely distressed areas, the average subgrade DCP blow counts ranged from 0.8 to 2.7 blows per inch of penetration. The moderately distressed areas exhibited average DCP blow counts ranged from 2.5 to 5.9 blows per inch of penetration. The areas showing no CIR distress had average blow counts ranging from 4.1 to 9.8 blows per inch of penetration. These data indicate that for subgrade stability the average DCP blow count for the top 12 inches of subgrade should be on the order of 5 blows per inch or greater.

**Figure 19: Average DCP Blow Count Data for each Distress Category**

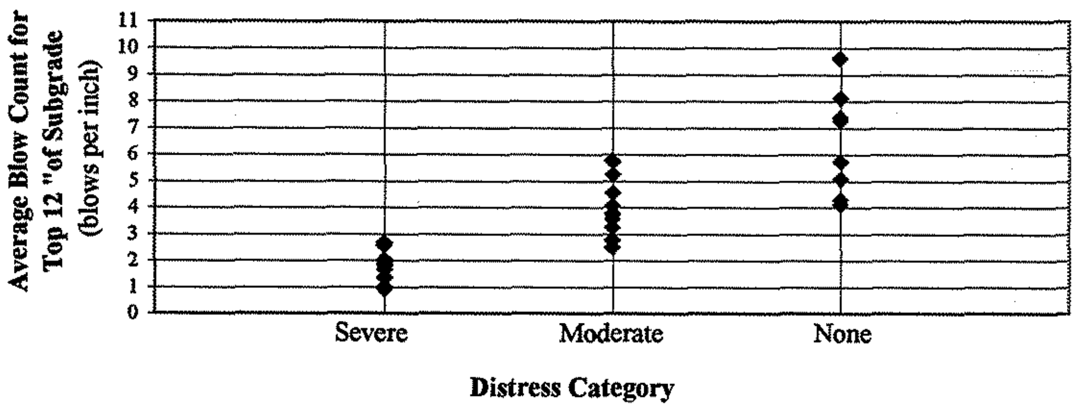


**Table 7: Blowcount Data**

| Distress Category | Minimum Blowcount (blows/in) | Average Blowcount (blows/in) | Maximum Blowcount (blows/in) |
|---|---|---|---|
| **Severe** | 0.8 | 1.7 | 2.7 |
| **Moderate** | 2.5 | 4.0 | 5.9 |
| **None** | 4.1 | 6.5 | 9.8 |

There appears to be no correlation between subgrade soil moisture content and distress category for this project. (Figure 20 and Table 8) The reason for this is probably because the soil type varied among test locations. Moisture affects each soil type in a different manner, and therefore can lead to differing levels of stability for differing levels of moisture.

**Figure 20: Moisture Contents of Each Test location for Each Distress Category**

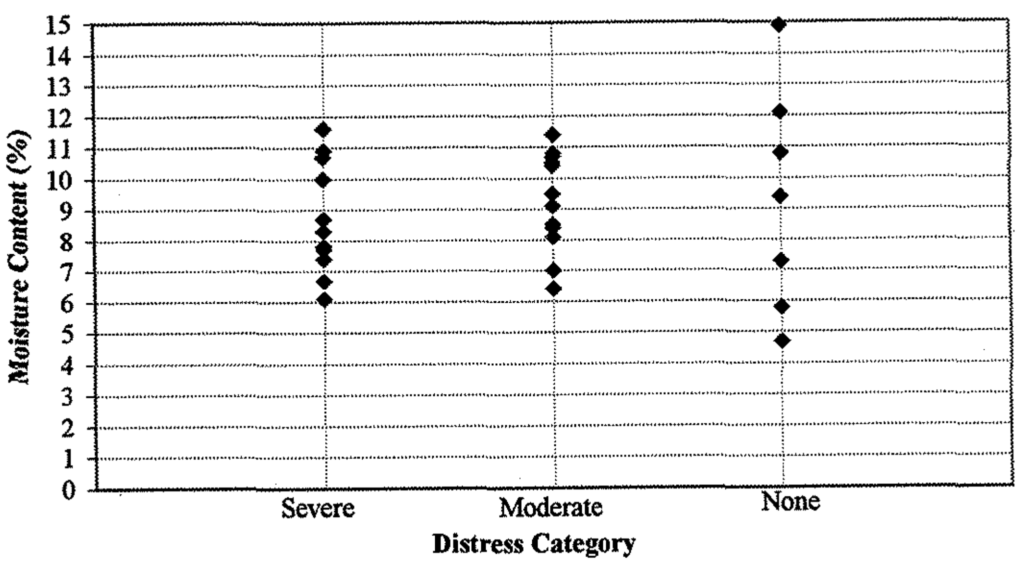



**Table 8: Moisture Contents for each Distress Category**

| Distress Category | Minimum Moisture Content (%) | Average Moisture Content (%) | Maximum Moisture Content (%) |
|---|---|---|---|
| **Severe** | 6.1 | 8.7 | 11.6 |
| **Moderate** | 6.4 | 9.2 | 11.4 |
| **None** | 4.7 | 9.5 | 14.9 |

The DCP test was also conducted at Iowa Highway 92 and Louisa County G40 in order to obtain data from projects where CIR experienced subgrade stability problems in the past. The precise locations where the equipment broke through were not known, but with the guidance of the people who inspected the projects, test locations were selected that were as close as possible to the areas of difficulty.

Most of the blowcounts at Iowa 92 (Table 9) were in the marginal range. It is evident that the subgrade strength may not be able to hold CIR equipment if it was attempted again. The conditions indicate that if DCP tests were conducted on this project before it began, CIR may not have been the chosen rehabilitation process.

**Table 9. Blowcounts from Iowa Highway 92**

| Test Location | Blowcount (blows/in) |
|---|---|
| 1 | 5.81 |
| 2 | 4.48 |
| 3 | 8.70 |
| 4 | 5.28 |
| 5 | 6.23 |
| 6 | 5.04 |

Two trips were made to Lousia County G40. The first trip was made in August of 1996. The testing equipment used for this trip was the soil cone penetrometer. The areas where failure occurred had low penetration to resistance, while areas where CIR was successful gave a low penetration resistance. One of the areas where failure occurred has numerous cattails and standing water in the ditches. In June of 1997, researchers returned to G40 and conducted DCP tests. The same areas that were tested during the previous trip were tested again. Results indicated that the regions where failure occurred gave results that indicated marginal subgrades, while others had a greater penetration resistance.

The pavement structure of the three projects where equipment "broke through" had no granular base. The construction records indicated that each project had a soil aggregate base; during the testing this was considered subgrade. Also, all of the projects were constructed early in the construction season, when the subgrade stability is likely to be low.

In an attempt to assess the usefulness of DCP testing for project selection, tests were conducted on five subgrades of pavements that were to be recycled during the 1997 construction season. (Table 10) Most of the blowcounts fell in a range that is suitable for CIR, although a few fell into the marginal range. All projects were completed without subgrade stability problems.

**Table 10. CIR Projects Constructed During 1997 Construction Season**

| Pavement | Amount of Base (in.) | Low Blowcount (blows/inch) | High Blowcount (blows/inch) |
|---|---|---|---|
| Benton Co. E22 | 6 | 6.14 | 12.6 |
| Bremer Co. C33 | 2 | 5.85 | 14.4 |
| Butler Co. T24 | 7 | 5.3 | 8.1 |
| Iowa 107 | 8 | 7.8 | 17.5 |
| Union Co. H17 | 4 | 5.4 | 15.6 |

**Recommended Test Guidelines**

The Dynamic Cone Penetrometer test should be performed on pavements during the project selection process. Recommended test guidelines are summarized in Figure 21 (a & b). Areas should be tested where subgrade stability is in question: heavily distressed pavement sections (especially sections exhibiting rutting, shoving, or potholes), places where evidence of moisture is nearby (cattails in ditches), or areas where pavement was placed directly on the natural soil. It requires drilling through the existing asphalt pavement and base material, while recording the thickness of each. The pointed end of the DCP is placed firmly on top of the subgrade. The falling weight is dropped and the penetration is recorded for each blow. This is repeated as a blow count is taken in the top 12 inches of the subgrade. This procedure should be done *at least* once per lane mile.

By evaluating the DCP blowcounts, engineering decisions can be made regarding the number frequency and locations. The DCP test can be used to determine if CIR is feasible and subgrade support is adequate.

The results of this study indicate that the dynamic cone penetrometer can be used prior to design and construction of a project to judge subgrade stability and the feasibility of CIR as a rehabilitation alternative. The test is inexpensive, quick, and easy to conduct.

**Figure 21(a). Recommended Guidelines for Evaluating CIR Construction Feasibility using Dynamic Cone Penetrometer (DCP) Testing.**

## PROJECT CANDIDATE

- Minimum of 5 to 6 inches of HMA pavement placed directly on subgrade soils or a soil aggregate base.①

## PROPOSED CONSTRUCTION

- CIR 3 to 4 inches of HMA, leaving approximately 2 inches of HMA to support recycling equipment.

## REQUIRED TEST EQUIPMENT

- Hammer drill, with 2 inch diameter masonry bit, minimum 12 inch bit length
- DCP 1.375 inch shaft, 15 pound weight, 20 inch drop, 45 degree cone.

## TEST TIMING

- It is recommended that feasibility testing be conducted in early spring, immediately after thaw, when subgrade conditions are at their weakest.
- This may be altered at the discretion of the engineer if actual construction will occur at times of better subgrade stability.

## TEST NUMBER AND LOCATION

- Initial testing should consist of a minimum of 2 tests per lane mile. The test should be located in areas where subgrade stability is questionable (i.e., heavily distressed areas, wet shallow ditch areas, cut areas, etc.).

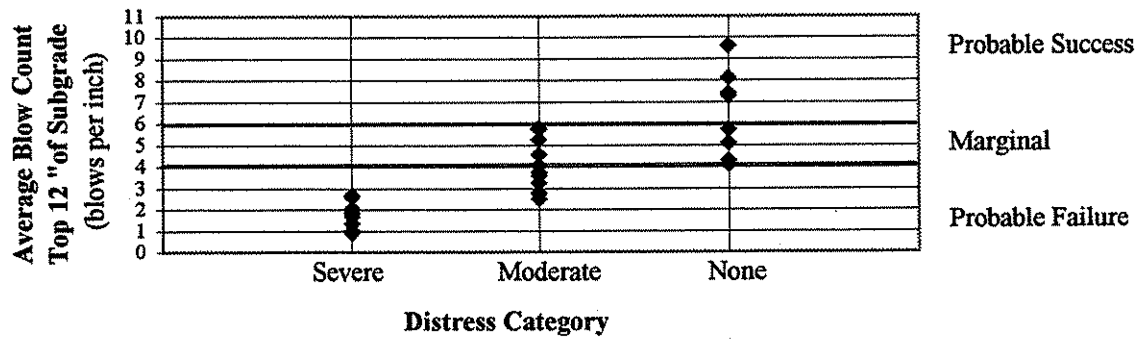
## TEST PROCEDURE

- Drill 2 inch diameter hole, record depth of HMA and base② (if present).
- Initiate the DCP test at the top of the subgrade soil or top of the soil aggregate base① (if present).
- Determine the average DCP blow count per inch of penetration for the top 6 and 12 inches of the subgrade.
  - → If the DCP blowcount per inch is increasing with depth up to 12 inches, discontinue the test at that depth.
  - → If the DCP blowcount per inch is decreasing with depth at 12 inches, continue the test to at least 18 inches.

**Figure 21(b). Guidelines for DCP test, continued.**

## Test Result Evaluation

- Calculate the average DCP blowcount per inch for the top 12 inches of subgrade soil.
- Compare the results with the figure shown below and determine feasibility for construction.




(Pleasant Creek State Park Data) ③

- If the majority of DCP counts fall in the "Probable Success Range", CIR is probably feasible.
- If the majority of DCP counts fall into the "Marginal Range", conduct additional testing to verify areas and locations on the project that are marginal. An engineering judgment must be made before deciding to proceed with CIR.
- If the majority of DCP counts fall into the "Probable Failure Range", it is unlikely that CIR is feasible. Consideration could be given to re-testing when subgrade conditions improve, if CIR could be scheduled during a time of improved subgrade condition.

① Results of this research indicated that soil aggregate subbases may not offer adequate structural support for CIR and should be considered as part of the subgrade for purposes of testing and evaluation.

② Results of this research indicate, in general, that if at least a 6 inch aggregate base is present it will likely provide adequate structural support for CIR equipment. The presence and thickness of the base, however, should be verified throughout the project.

③ From DCP testing results obtained to date on Iowa CIR projects, the ranges given are believed to be valid.

## CONCLUSIONS AND RECOMMENDATIONS

A systematic performance study has been conducted on a representative sample of CIR roads in Iowa. They have been rated both qualitatively and quantitatively. The performance of the roads over the last ten years has been generally good. Few rutting distresses have been noted. The rutting distresses that have been experienced are likely due to construction problems, unfavorable weather during construction, inadequate base or subgrade conditions. CIR appears to be effective in mitigating transverse cracking. It is recommended that pavement performance be measured by averaging a quantitative [PCI] evaluation and a qualitative [PSI] evaluation. This measurement method was used to estimate the life of a CIR road 15 to 26 years. In making this prediction it was assumed that the relationship between age and pavement index is linear and the service life ends when the pavement index reaches 25.

Past experience has shown the subgrade instability is the worst problems that a CIR project is likely to face in Iowa. Out of more than 100 projects, only three have been stopped by this problem. Because this is a critical problem, researchers developed a test that could be used to quickly and inexpensively detect unstable subgrades. This test involves drilling a hole in the pavement with a hammer drill and taking a blow count with a dynamic cone penetometer. This test is recommended for future CIR projects in Iowa.

**Specific Conclusions are as follows:**

1. A performance evaluation should be a combination of a systematically conducted quantitative distress survey and a qualitative rating based on ride and appearance.

2. In general, performance of CIR roads in Iowa has been good. Current design and construction procedures appear to be adequate.

3. Little rutting has been noted. Places where rutting is noticeable are likely caused by construction problems, unfavorable weather conditions during construction, inadequate base or subgrade conditions.

4. CIR appears effective in mitigating cracking. Little cracking occurs in the first five years of a typical road's life. When cracks do develop, they have a lower frequency when compared to the road before it was recycled.

5. CIR has been successfully used to widen the road. (Tama and Cerro Gordo Counties).

6. The predicted service life is 15 to 26 years based on a terminal index of 25.
7. A four inch depth of recycling is equivalent in cost to one inch of hot mix overlay.
8. Subgrade stability is the single most important factor in determining CIR construction feasibility.
9. Dynamic cone penetrometer (DCP) testing conducted at the CIR project in Pleasant Creek State Park established baselines for evaluating subgrade stability requirements for CIR. These baselines were checked at other project locations.
10. DCP testing must be conducted under moisture conditions that will be similar to those anticipated during the construction season.

**<u>Recommendations for CIR Projects:</u>**

1. Continue current design and construction procedures.
2. Conduct DCP tests in areas where subgrade stability is a concern.
3. CIR to a maximum depth of four inches
4. In most cases, it is desirable to leave at least an inch (preferably 2) of existing asphalt as a base for machine support or compaction. Projects have been successfully completed that leave less when subgrade stability is good.
5. It is desirable to minimize the amount of unrecycled asphalt remaining under the recycled mat in order to minimize reflective cracking.
6. CIR can be considered for roads that have dry, cracked, aged asphalt over a stable base.
7. CIR can be considered to address minor cross section irregularities.
8. CIR should not be considered with roads that have problems with subgrade stability. Reclaiming should be considered instead.

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## APPENDIX A: RESEARCH STEERING COMMITTEE MEMBERS

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|---|---|
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| Brian Ellsworth | Research Assistant, ISU |
| Frank Farmer, P.E. | City of Fort Dodge Engineer |
| Robert Gumbert, P.E. | Tama County Engineer |
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| Charles Jahren, P.E., Ph.D. | Assistant Professor, ISU Civil Engr. |
| Don Jordison, P.E. | Exec. VP Asphalt Paving Assoc of Iowa |
| Larry Mattusch, P.E. | Scott County Engineer |
| Renee White | Asphalt Paving Association of Iowa |
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## APPENDIX B: GLOSSARY

- *Asphalt Overlay* is one or more courses of asphalt construction on an existing pavement.
- *Asphalt Surface Course* is the top (or wearing) course of an asphalt pavement.
- *Cold In-Place Asphalt Recycling (CIR)* is the process of rehabilitating an asphalt road where the road exists using a cold mix made up of aggregates from the existing road.
- *Distress* is a condition of the pavement structure or surface, which reduces the serviceability or leads to a reduction of serviceability.
- *Distress index* is a numerical rating for the quality and quantity of distress present.
- *Distress manifestations* are the visible consequences of various distress mechanisms.
- *Mixed-in-Place (Road Mix)* is an asphalt course produced by mixing mineral aggregate and cutback or emulsified asphalt at the road site by means of traveling plants, motor graders, or special road mixing equipment.
- *Pavement condition index (PCI)* is a quantitative method of evaluating the pavement's physical condition as a function of distress type, severity, and quantity present.
- *Performance* is a measure of accumulated service provided by a facility. In other words, the degree to which a pavement fulfills its purpose.
- *Present serviceability index (PSI)* is a qualitative method of evaluating the serviceability of a pavement as determined by a panel of one or more raters.
- *Stability* is a measure of the capacity and reliability of a structure to handle loading.
- *Subbase* is the course in the asphalt pavement structure immediately below the base course.
- *Subgrade* is the soil prepared to support a structure or a pavement system.
- *Subgrade (Improved)* is subgrade, improved as a working platform (1) by the incorporation of granular materials or stabilizers such as asphalt cement, emulsion or cutback, lime, or Portland cement, prepared to support a pavement or structure system, or (2) any course or courses of select or improved material placed on the subgrade soil below the pavement structure.
- *Serviceability* is the ability of a specific section of pavement to serve traffic in its existing condition.
- *Serviceability index* is a numerical rating of serviceability of the pavement to the user.

# Appendix C: Construction Data

| County | Road | Age | AADT | CIR Contractor | Start Date | Finish Date | Asphalt Existing(in) | Base (in) | CIR (in) | CIR Milled % | Emulsion | Overlay (in) | Asphalt | AC % | Void % | Mix (in) | Rutting | T-crk /mile | (PCI+PSI) /2 | Perf.[1] Category | Native Soil[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muscatine | G-28 | 5 | 940 | W-K | 15-Sep | 22-Sep | 8 | 6 | 4 | 50 | CSS-1 | 2 | AC-5/10 | 4.9 | 4.5 | 0.75 | 0 | 2 | 85.3 | A | 3 |
| Tama | V-18 | 5 | 550 | Koss | 24-Sep | 11-Jul | 0 | 6 | 4 | 67 | HF-300RP, CSS-1 | 2 | AC-5 | 6.1 | 6.5 | 0.5 | 0 | 0 | 85 | A | 2 |
| Boone | E-52 | 5 | 290 | W-K | 25-Jun | 28-Jun | 8 | 6 | 4 | 50 | CSS-1 | 2 | AC-10 | 5.1 | 4 | 0.5 | 0 | 2 | 84 | A | 1 |
| Clinton | Z-30 | 7 | 850 | W-K | 13-Jun | 19-Jun | 5 | 10 | 4 | 80 | CSS-1 | 2 | AC-10 | 6.5 | 6 | 0.5 | 0 | 1 | 80.4 | A | 2 |
| Muscatine | F-70 | 3 | 950 | W-K | 26-Aug | 20-Sep | 4 | 8 | 4 | 100 | CSS-1 | 3 | AC-5 | 5.7 | 7 | 0.5 | 0 | 0 | 90.8 | B | 3 |
| Butler | T-16 | 3 | 470 | Koss | 26-Jul | 10-Aug | 6 | 6 | 4 | 67 | CSS-1 | 2 | AC-5 | 5.5 | 7 | 0.5 | 0 | 0 | 90.7 | B | 2 |
| Tama | E-66 | 6 | 1080 | Koss | 12-Jul | 28-Jul | 4 | 8(pcc) | 4 | 100 | HF-300RP | 2 | AC-5 | 5.9 | 7 | 0.5 | 0 | 6 | 77.7 | B | 2 |
| Clinton | E-50 | 10 | 520 | W-K | na | 20-Aug | 5.5 | 6.5 | 4 | 73 | CSS-1 | 2 | AC-10 | 5.1 | 4 | 0.5 | 10 | 15 | 65.7 | B | 2 |
| Winnebago | R-34 | 6 | 620 | Mathy | 18-Jul | 30-Jul | 6 | 6 | 4 | 67 | HF-300RP | 2 | AC-5 | 5.7 | 4.1 | 0.5 | 0 | 10 | 76.3 | C | 1 |
| Cerro-Gordo | B-43 | 7 | 570 | W-K | 30-Jul | 7-Aug | 6 | 6 | 4 | 67 | CSS-1 | 2 | AC-10 | 5.2 | 5.6 | 0.5 | 8 | 3 | 71.3 | C | 2 |
| Boone | 198TH | 8 | 300 | Mathy | na | na | 6 | 6 | 4 | 67 | CSS-1 | 2 | AC-10 | 5.7 | 3.6 | 0.5 | 17 | 0 | 65.4 | C | 1 |
| Hardin | D-35 | 4 | 665 | Mathy | 9-Jul | 20-Jul | 6.5 | 6 | 3 | 46 | CSS-1 | 2 | AC-10 | 5.5 | 6.5 | 0.5 | 3 | 8 | 75 | D | 1 |
| Cerro-Gordo | S.S | 6 | 600 | W-K | 8-Aug | 17-Aug | 8 | 6 | 4 | 50 | CSS-1 | 2 | AC-10 | 6.2 | 5 | 0.5 | 1 | 14 | 71.2 | D | 3 |
| Winnebago | R-60 | 6 | 340 | Mathy | 13-Jul | 18-Jul | 5 | 6 | 4 | 80 | HF-300RP | 2 | AC-5 | 5.5 | 4.3 | 0.5 | 0 | 0 | 67.3 | D | 1 |
| Muscatine | Y-14 | 9 | 990 | Brown&Brown | 22-Jun | 4-Jul | 6 | 6 | 4 | 67 | HFE-150S, CSS-1, HFMS | 2.5 | AC-10 | 6 | 5.75 | 0.75 | 9 | 7 | 57.4 | D | 3 |
| Calhoun | IA-175 | 3 | 1920 | na | na | na | 8 | 8 | 3 | 38 | CSS-1 | 4.5 | na | na | na | na | 0 | 0 | na | na | na |
| Greene | IA-144 | 7 | 1110 | na | na | na | na | na | na | na | na | na | na | na | na | na | 17 | 7 | na | na | na |
| Guthrie | IA-4 | 3 | 820 | na | na | na | na | na | na | na | na | na | na | na | na | na | 0 | 0 | na | na | na |

1. Performance Category can be defined as:

A. Performance exceeds 95% confidence interval (Figure 7).
B. Performance above the regression line but below the upper 95% confidence limit.
C. Performance below the regression line, but above the lower 95% confidence limit
D. Performance below the 95% confidence limit.

2. Native Soil is defined from different geological regions:

Area 1 -Fresh glacial drift, no loess cover, areas of level terrain
Area 2 - Thin, discontinuous loess or loam over drift, gently rolling terrain
Area 3 - Alluvial features, thick sequences of clay, silt, sand and gravel.

## APPENDIX D: PSI RATING SCALE

Highways are for the comfort and convenience of traveling public. Considering this, a method of evaluating the qualitative performance of the road was established at the beginning of the project to qualitatively survey the roads.

### Ride Rating

10: New - No roughness or cracks.
9:
8: Minor roughness. Cracks cannot be felt while driving
7:
6: Noticeably rough. Cracks can be felt while driving.
5:
4: Very rough.
3:
2: Extremely rough. Difficult to maintain speed because of roughness.

### Appearance Rating

10: Looks dark and smooth.
9:
8: Minor cracks are barely visible.
7:
6: Cracks are clearly visible, weathered surface.
5:
4: Transverse cracks at short intervals. Longitudinal cracks present.
3:
2: Heavily distressed, transverse, longitudinal, and block cracking present.

## APPENDIX E: PLEASANT CREEK STATE PARK TEST LOCATIONS