Detection of Concrete Delamination

By Infrared Thermography

Final Report
Iowa Highway Research Board
Project HR-244

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Iowa Department of Transportation

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BY

INFRARED THERMOGRAPHY

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By

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INTRODUCTION

Iowa has approximately 1000 bridges that have been overlaid with a nominal 2" of portland cement concrete. A Delamtect survey of a sampling of the older overlaid bridges indicated delaminations in several of them. Eventually these bridges as well as those that have not received an overlay must be programmed for rehabilitation.

Prior to rehabilitation the areas which are delaminated must be identified. There are currently two standard methods of determining delaminated areas in bridge decks; sounding with a metal object or a chain drag and sounding with an electro-mechanical sounding system (Delamtect). Sounding with a metal object or chain drag is time consuming and the accuracy is dependent on the ear of the operator and may be affected by traffic noise. The Delamtect requires less field time but the graphical traces require that data reduction be done in the office.

A recently developed method of detecting delamination is infrared thermography. This method is based on the temperature difference between sound and delaminated concrete.

A contract was negotiated with Donohue and Associates, Inc. of Sheboygan, Wisconsin, to survey 18 p.c. concrete overlaid bridge decks in Iowa using the infrared thermography method of detecting delaminations.

OBJECTIVES

The objectives of the project were to assess the accuracy, dependability, and potential of infrared thermography for detecting delamination on p.c. overlaid bridge decks and bonded overlays of PCC pavement.

PROCEDURE

An infrared scanner and a color video camera were mounted on a van a maximum of 17 feet above the pavement. The van housed video recorders and monitors so that both the real life image and the infrared image could be recorded and monitored during testing. The survey was made during the week of June 14, 1982.

The van was driven across the bridge at a speed of about 5 mph. After scanning a portion of the bridge, the van was located at an area suspected of being delaminated for system calibration. Calibration was accomplished by confirming a delaminated area by sounding with a hammer and then taking the surface temperature of the delaminated area and a non-delaminated area. After collection of the calibration data, the remainder of the deck was tested.

Photographic strip charts were produced by channeling the video signal through a series of instruments. The infrared and the real life control charts were placed side by side and suspect delaminations were marked on the infrared chart and then checked against the control chart to make sure that the suspect area was not an asphalt patch, concrete discolored by oil drippings, or debris along the curb.

The area of delamination was then calculated and reported as a percent of the bridge deck delaminated.

EVALUATION

Thirteen bridge decks that were surveyed with infrared thermography were also tested with the Delamtect. Table I generally shows a large difference between the infrared method and the Delamtect method in the percentage of delamination in each bridge deck. No specific effort was made to identify the depth of the delamination in the deck. However, when delaminations occur in overlaid bridge decks in Iowa, it is common for the delamination to be in the underlying concrete within approximately 1/4" of the bond line.(1)

TABLE I
COMPARISON OF INFRARED & DELAMTECT

Bridge	% Delaminated Infrared	% Delaminated Delamtect	Sky Condition	Temp. Diff.(^{o}F)
US 65 over US 30	20.25	30.51	Clear	3.5
IA 141 over Little Beaver Cr.	9.25	13.35	Ptly Cldy	2.0
I-35 SB over Raccoon	0.60	0.45	Cloudy	1.0
I-35 NB over Raccoon	0.15	0.28	Ptly Cldy	1.0
9th Street over I-235	12.30	10.64	Clear	4.5
IA 175 over I-29	7.85	17.52	Clear	1.0
US 20 over Elliott Creek	0.85	10.32	Clear	2.0
US 75 over Floyd River	4.50	14.15	Clear	2.0
IA 3 over Mink Creek	8.50	6.88	Clear	1.0
IA 3 over W. Branch Floyd R.	3.50	12.49	Clear	1.0
IA 3 over Little Sioux	5.90	33.03	Ptly Cldy	1.5
US 59 over Gray Creek (225')	9.20	17.73	Ptly Cldy	2.0
US 59 over Gray Creek (102')	0.80	12.59	Ptly Cldy	1.5

Table II shows the results of drilling cores from four bridge decks at locations where there was disagreement between the infrared method and the Delamtect. The condition was accurately indicated by the Delamtect at all the test areas. A Delamtect plot and infrared chart for the same bridge are shown in figures 1 and 2 respectively. Similar plots were made for each bridge surveyed in this project. Those plots, as well as additional narrative in a separate report from Donohue & Associates, are available in the Research Section of the Office of Materials.

US-59 OVER GRAY CREEK (102')
Both Lanes
August 10, 1982

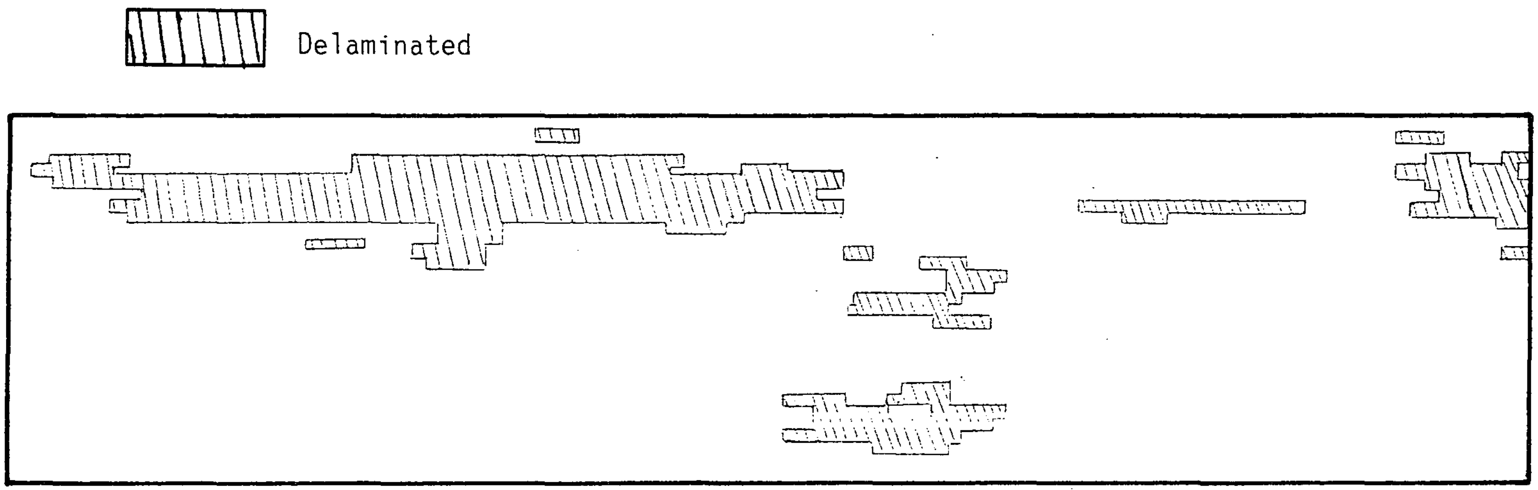


Figure 1: Delamination Plot from Delamtect Chart

US 59 OVER GRAY CREEK
BOTH LANES (102')

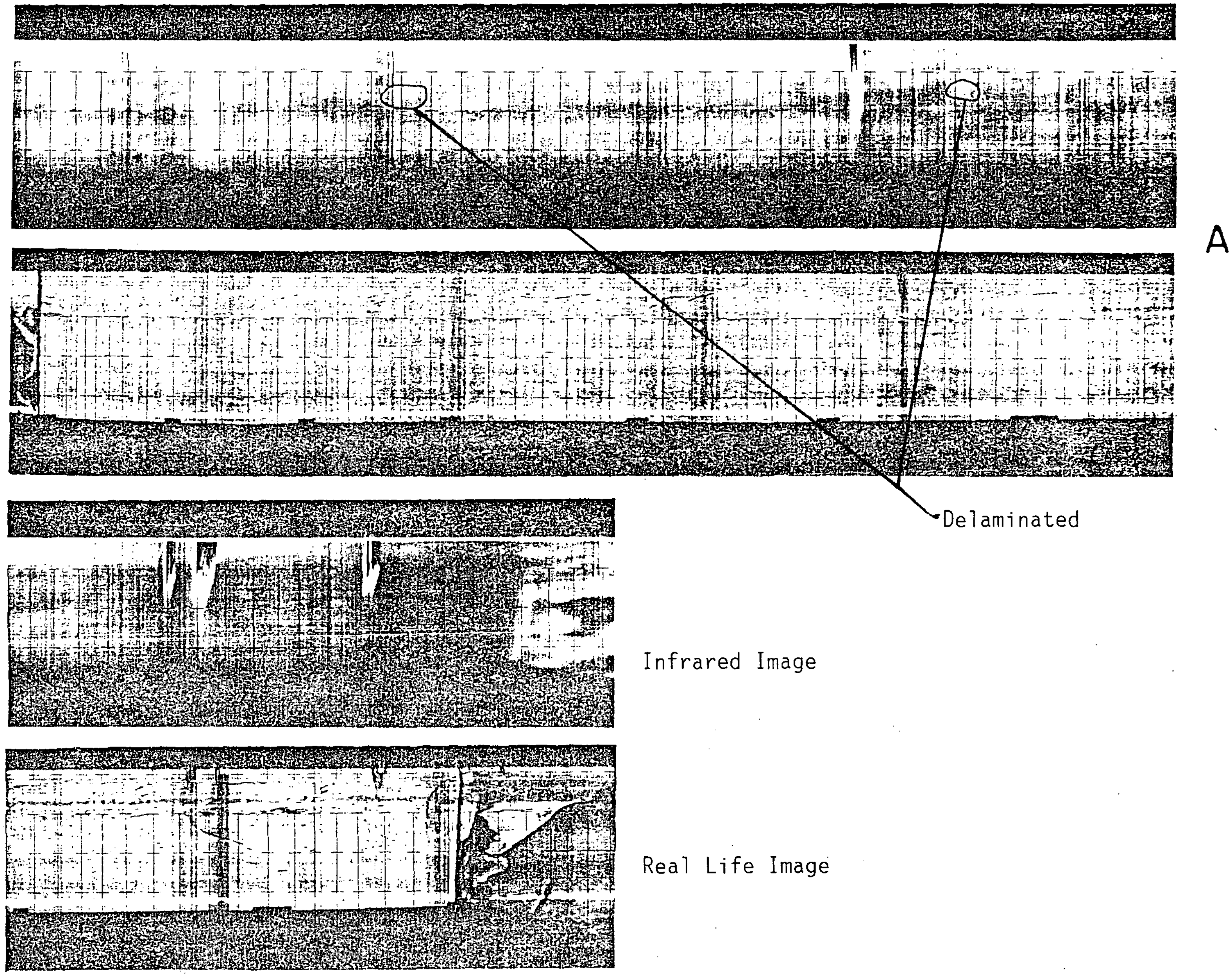


Figure 2: Photographic Strip Charts

TABLE II
INFRARED-DELAMTECT-CORE COMPARISON FOR DELAMINATION

Bridge	Infrared	Delamtect	Core
US 65/US 30	Yes	No	No
9th St./I-235	Yes	No	No
US 20/Elliott Cr.	No	Yes	Yes
IA 175/I-29	No	Yes	Yes

The infrared system generally indicated less delamination in bridge decks than did the Delamtect.

The I-80 thin bonded pcc overlay in Pottwattamie County was also surveyed with the infrared system. No delamination was observed by infrared thermography. The Delamtect was run in the outside wheelpath for comparison and no delamination was found. Since apparently there was no delamination, it was not possible to determine the accuracy of the infrared system for locating delaminations in bonded pcc overlays from this project.

DISCUSSION

Infrared thermography would be ideally suited for surveying large areas of bonded pcc overlays or large bridge decks if it could be determined to be reliable. Accurate delamination determination by infrared thermography is dependent on the temperature differential between delaminated and sound concrete. The greater the differential, the easier it is to identify delaminations. It may be that shallow delaminations can be identified and deeper delaminations not identified in the same bridge deck because the temperature differential for the deeper delamination might be insufficient for identification.

Ideal conditions for infrared surveying are dry pavement, clear skies, and winds below 15 mph. As evidenced in Table I, these conditions were not always present during this project. Sky conditions were sometimes partly cloudy and according to the field data sheets, wind velocity was sometimes above 15 mph.

Although the infrared data can be computer enhanced, interpretation is very subjective. Two people could easily disagree on what is delaminated. This may be especially so on east-west bridges where the deck temperatures may be affected by barrier rail shadows. The barrier rail shadows would also narrow the window for surveying as the sun would have to be higher in the sky to reduce shadows.

Weather conditions in Iowa (Appendix) are such that optimum conditions, clear skies and winds less than 15 mph are of such short duration that it would be impractical for the Iowa Department of Transportation to purchase this type of equipment. It would not be possible to have productive work available for a survey crew if it were sent to a location and the weather became windy or cloudy preventing infrared surveying.

It is difficult to determine exact locations of delaminations and number of square feet as the photographic charts are not conveniently scaled. The results are reported as a percentage of the test area.

This type of testing is suited for large scale studies such as pavements or large bridges such as those over the Missouri and Mississippi Rivers. If it were desired that this type of testing be undertaken it would be recommended that it be done by an outside firm and the testing firm be made responsible for selecting optimum testing conditions and the resulting accuracy.

CONCLUSIONS

The following conclusions can be made from this study.

1. Ownership of this type of equipment by the Iowa DOT is not practical because weather conditions in Iowa are not conducive to the efficient use of personnel and equipment.

2. In this study, infrared thermography detected less delamination on bridge decks with a bonded overlay than did the Delamtect.

3. Cores drilled from bridge decks verified that the Delamtect was more accurate in locating delaminations than was the infrared thermography system. Whether this would hold true during ideal testing conditions is not known.

4. The accuracy of infrared thermography in locating unbonded areas of thin bonded pcc pavement was not determined by this project. The process, however, does seem well suited to surveying large areas of this type.

ACKNOWLEDGEMENT

This research was sponsored by the Iowa Department of Transportation through the Iowa Highway Research Board. Funding for this project was from the Primary Road Research fund in the amount of $9700.

REFERENCE

1. Brown, B. C., A Further Evaluation of Concrete Bridge Deck Resurfacing in Iowa, March 1979.

APPENDIX

Iowa Department of Agriculture

R. H. LOUNSBERRY
SECRETARY OF AGRICULTURE

THATCHER JOHNSON
DEPUTY SECRETARY OF AGRICULTURE

IOWA WEATHER SERVICE
Room 10 Terminal Building
Municipal Airport
Des Moines, Iowa 50321

HENRY A. WALLACE BUILDING
DES MOINES, IOWA 50319

May 17, 1983

Mr. Bernard C. Brown, Testing Engineer
Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010

Dear Mr. Brown:

From the Local Climatological Data, Des Moines, Iowa and the Airport Climatological Summary (1965-1974) Des Moines, Iowa, I've prepared the attached table as one representative for Iowa. Northeast Iowa is normally cloudier and western Iowa sunnier than Des Moines. Similar information could be extracted for other sites in and around Iowa at a small cost.

The tabular distribution of number of days with the three categories of winds are set forth at 3:00 p.m. CST since winds are normally highest from about noon to 3 p.m. The noon distribution is virtually the same. However, frontal passages and normal movement of high and low pressures often cause daily variation from the average pattern (also enclosed as copied from Winds Over Iowa).

Sincerely,

Paul Waite
Paul Waite
State Climatologist

Des Moines, Iowa

10 yr. Average Number Days Wind speeds @ 1500CST				Cloudy Days 8, 9, 10 tenths Coverage	By Year # Days Wind >15 MPH				By Year Number Days 10 Tenths Clouds Dawn to Sunset			
	MPH											
Month	≤12	13-18	≥19		1982	1981	1980	1979	1982	1981	1980	1979
May	11.3	16.1	3.6	15	22	23	22	23	12	11	4	4
June	14.5	13.0	2.5	11	20	23	20	21	3	5	2	5
July	19.6	10.1	0.6	9	18	19	21	15	2	4	0	6
Aug.	19.9	10.1	1.0	10	16	15	22	18	5	2	4	3
Sept.	16.4	12.6	1.0	11	14	19	20	13	5	1	2	0

summed by day and month to obtain averages which are reconverted into a single vector and printed in the Local Climatological Data (LCD).

The mean annual resultant winds (Figure 4) indicate a general southwest flow across Iowa indicated on the map as 24 on the 36 points of the compass. The mean average resultant transport averages about one mile per hour increasing from west to east across Iowa. This seasonal pattern is a result of the north-south shifting of the jet stream, thus putting Iowa under the spell of the northern polar air masses in winter and the lower latitudinal air mass in summer.

Figure 3.
Mean Cool Season (November-April) Wind Directions and Speeds (mph)

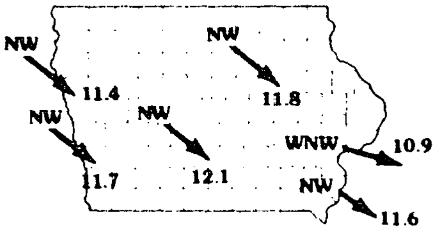
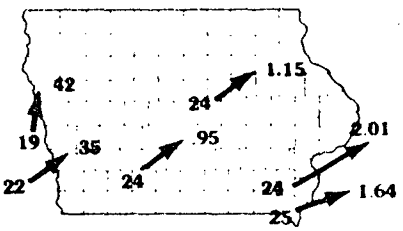


Figure 4.
Mean Resultant Winds: Directions and Speeds (mph) 1969-1978



By averaging the wind speeds across the State, a monthly profile has been obtained. April is the windiest month with the highest mean wind speed of 12.8 mph and August is the least windy with an average of 8.3 mph. Annually Iowa averages 10.5 mph. The March-April peak coincides with the passing of winter into summer and the proximity of prevailing storm tracks over Iowa. A secondary peak in November occurs with the re-establishment of winter (Figure 5).

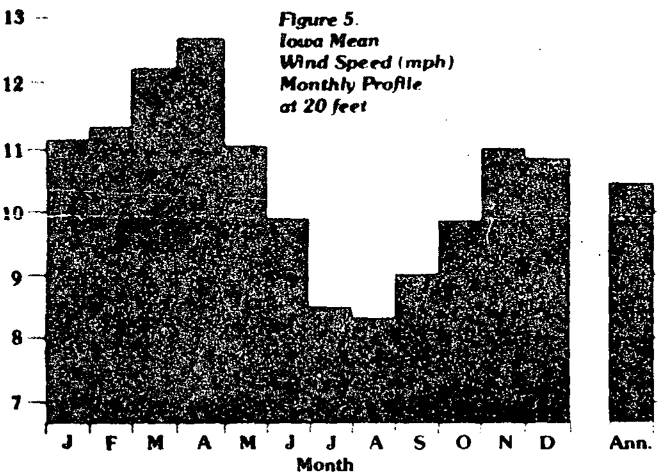


Figure 5.
Iowa Mean Wind Speed (mph) Monthly Profile at 20 feet

Since winds are dependent on the solar radiation rate of differential heating, one might expect the lightest winds to be during early morning when it is coolest and the strongest winds occurring in the afternoon when it is warmest, following the diurnal temperature cycle. The winds of Iowa follow this pattern. For Iowa, we see the low in the cycle at 6:00 a.m. of 8 mph and the high of 13 mph at 3:00 p.m. annually (Table 4). Des Moines seems to be windier than either Moline or Omaha (Table 5). For April, the windiest month, 10.3 mph is the low point in the cycle reported at 3:00 a.m. and the high point of 15.2 mph is reported at 3:00 p.m. August, the least windy, has a low of 6.3 mph at 3:00 a.m. and the high point of the cycle reaches 10.9 mph at 3:00 p.m. December, the month most near average, records a low of 9.8 mph at 3:00 a.m. and the high reaches 12.4 mph at 3:00 p.m. (Figure 6). The passing of a low pressure will alter the diurnal pattern of wind, with higher winds being recorded during the passage.

Table 4. Iowa Mean Wind Speed (mph), Diurnal and Monthly Values (3 Site Average, 1969-78)

Hour	00	03	06	09	12	15	18	21	Monthly
January	11	10	10	11	13	13	11	11	12
February	10	10	10	10	13	13	11	10	11
March	10	10	10	13	14	14	12	11	12
April	10	10	10	13	15	15	13	11	13
May	8	8	8	11	13	13	13	8	11
June	7	7	8	11	12	12	11	8	11
July	7	7	6	9	11	11	10	7	8
August	6	6	6	9	10	11	9	6	8
September	7	7	7	10	11	11	8	7	9
October	8	7	8	10	12	12	9	8	10
November	9	9	9	11	13	13	10	10	11
December	10	9	10	10	12	12	10	10	11
Hourly	8	8	8	11	12	13	11	9	11 Annual

Table 5. Iowa Mean Wind Speed (mph), Diurnal and Monthly (1969-78)

A. Des Moines

Hour	00	03	06	09	12	15	18	21	Monthly
January	12	11	11	12	13	13	11	11	12
February	11	11	10	11	13	14	11	10	12
March	11	11	11	13	14	14	12	11	13
April	11	10	11	13	15	15	13	11	13
May	8	8	9	12	13	13	12	9	12
June	8	8	8	11	13	13	11	8	10
July	7	7	7	10	11	11	10	7	9
August	7	7	7	9	11	11	9	7	9
September	8	7	8	10	11	11	9	8	10
October	8	8	8	10	12	13	9	9	11
November	10	9	10	11	13	13	10	10	12
December	10	9	10	11	13	13	11	10	12
Hourly	9	9	9	11	13	13	11	9	11 Annual

B. Omaha

Hour	00	03	06	09	12	15	18	21	Monthly
January	10	10	10	10	12	12	11	11	11
February	10	10	9	10	13	13	11	10	11
March	10	10	10	12	13	14	13	10	12
April	10	10	10	13	14	15	14	11	13
May	8	8	8	11	12	12	11	8	11
June	7	7	7	10	12	12	11	8	10
July	7	7	7	9	11	11	10	7	9
August	6	6	6	9	10	11	10	7	9
September	7	7	7	9	10	12	9	7	10
October	7	7	7	10	12	12	9	8	10
November	9	9	9	10	13	13	10	9	11
December	9	9	9	10	11	12	10	9	11
Hourly	8	8	8	10	12	13	11	9	11 Annual

C. Moline

Hour	00	03	06	09	12	15	18	21	Monthly
January	11	10	10	11	13	13	11	11	11
February	9	10	10	11	13	13	11	10	11
March	10	10	10	13	14	15	12	11	12
April	10	10	10	13	15	15	12	10	12
May	7	7	8	11	13	13	11	8	10
June	7	7	8	11	12	12	11	7	9
July	6	6	5	9	11	11	9	6	7
August	5	5	5	9	10	10	8	5	7
September	6	6	6	10	11	11	7	6	8
October	8	7	8	11	12	12	8	8	9
November	9	9	9	11	12	12	10	10	10
December	10	9	10	10	12	12	10	10	10
Hourly	8	8	8	11	12	12	10	9	10 Annual