

2009

# Structural evaluation of rubblized concrete pavements in Iowa

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## Recommended Citation

Ceylan, Halil; Gopalakrishnan, Kasthurirangan; and Kim, Sunghwan, "Structural evaluation of rubblized concrete pavements in Iowa" (2009). *Civil, Construction and Environmental Engineering Conference Presentations and Proceedings*. 12.  
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# Structural evaluation of rubblized concrete pavements in Iowa

## **Abstract**

Rubblization is one of the surface preparation techniques before placing a Hot Mix Asphalt (HMA) overlay that involves breaking the Portland Cement Concrete (PCC) pavement into pieces. This paper describes the structural assessment related to the long term performance of rubblized concrete pavements in Iowa. The structural performance of seven representative in-service rubblized concrete pavement sections across Iowa were evaluated through Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP) tests, and visual pavement distress surveys. Through backcalculation of FWD deflection data using the Iowa State University (ISU) layer moduli backcalculation program, the pavement layer moduli values were determined and were correlated with the long-term pavement performance. The backcalculated subgrade modulus values were also compared with the subgrade modulus values obtained from DCP test results. The results indicate that the rubblized pavement sections in Iowa are performing very well. It is recommended that the rubblized pavements be frequently monitored to gain a better understanding of their long-term performance.

## **Keywords**

back calculation, deflection data, dynamic cone penetrometer, falling weight deflectometer, hot mix asphalt, long term performance, pavement distress, pavement layer, Portland cement concrete pavements, rubblization, structural evaluation

## **Disciplines**

Civil and Environmental Engineering | Construction Engineering and Management

## **Comments**

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**Reference** to this paper should be made as follows: Ceylan, H., Gopalakrishnan, K., and Kim, S. “*Structural Evaluation of Rubblized Concrete Pavements in Iowa*,” 8th International Conference on the Bearing Capacity of Roads, Railways, and Airfields, June 29-July 2, 2009, Champaign, Illinois.

## **Structural Evaluation of Rubblized Concrete Pavements in Iowa**

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### **ABSTRACT**

Rubblization is one of the surface preparation techniques before placing a Hot Mix Asphalt (HMA) overlay that involves breaking the Portland Cement Concrete (PCC) pavement into pieces. This paper describes the structural assessment related to the long term performance of rubblized concrete pavements in Iowa. The structural performance of seven representative in-service rubblized concrete pavements sections across Iowa were evaluated through Falling Weight Deflectometer (FWD) tests, Dynamic Cone Penetrometer (DCP) tests, and visual pavement distress surveys. Through backcalculation of FWD deflection data using the Iowa State University (ISU) layer moduli backcalculation program, the pavement layer moduli values were determined and were correlated with the long-term pavement performance. The backcalculated subgrade modulus values were also compared with the subgrade modulus values obtained from DCP test results. The results indicate that the rubblized pavement sections in Iowa are performing very well. It is recommended that the rubblized pavements be frequently monitored to gain a better understanding of their long-term performance.

### **INTRODUCTION**

An asphalt overlay of a fractured concrete pavement has become an alternative rehabilitation strategy that many agencies are now using instead of total reconstruction for heavily distressed Portland Cement Concrete (PCC) pavements. Slab fracturing may be done for two reasons: to attempt to mitigate reflection cracking in the overlay, and/or to dispense with pre-overlay repair of a concrete pavement with extensive cracking and/or materials-related deterioration (e.g., “D” cracking, alkali-silica reaction, alkali-carbonate reaction, etc.). Several surface preparation techniques have been used before placing a Hot Mix Asphalt (HMA) overlay in attempts to minimize reflection cracking. Some of the most common techniques are rubblization, crack-and-seat, break-and-seat, and saw-and-seal (Hall et al. 2001).

Rubblization is an in-place rehabilitation technique that involves breaking the concrete pavement into pieces. The sizes of the broken pieces usually range from sand size to 75 mm (3 in) at the surface and 305 to 381 mm (12 to 15 in) on the bottom part of the rubblized layer (Von Quintus et al. 2007). The rubblized PCC pavement behaves like a high-quality granular base layer and it responds as an interlocked unbound layer – reducing the existing PCC to a material comparable to a high-quality aggregate base course. This loss of structure must be accounted for in the HMA overlay design thickness (Galal et al. 1999). The results from a comprehensive investigation conducted by PCS/Law (PCS/Law 1991), the National Asphalt Pavement Association (NAPA) study (NAPA 1994), and a nationwide survey conducted by the Florida Department of Transportation (DOT) (Ksaibati et al. 1998) all indicate that rubblization is the most utilized procedure for addressing reflection cracking (Heckel 2002; LaForce 2006).

More than 50 million square yards of U.S. highways has been successfully rubblized between 1994 and 2002 since the first project in New York in 1986 (Von Quintus et al. 2007). The performance experience of rubblization have also been studied in a considerable number of states including Illinois (Thompson 1999, Heckel 2002, Wienrank and Lippert 2006), Indiana (Gulen et al. 2004), Wisconsin (Von Quintus et al. 2007), Michigan (Baladi et al 2002; APTEch 2006), Alabama (Timm and Warren 2004), Ohio (Rajagopal 2006), Arkansas (Rajagopal 2006),

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Colorado (LaForce 2006), and Texas (Sebesta and Scullion 2006; Scullion 2006).

The results of these studies indicated that the performance of rubblization technique varied from place to place and from project to project. The variation is due to factors such as the condition of the existing PCC pavement, type and level of distress, type of construction equipment, environmental conditions, traffic, and type and thickness of HMA overlay. In addition, many agencies are considering the use of mechanistic-based design procedures, such as the Mechanistic Empirical Pavement Design Guide (MEPDG) developed under NCHRP 1-37A (NCHRP 2004) for overlay design procedure. Even though the modulus for the rubblized layer is an important design value in MEPDG to determine the thickness of the HMA overlay, those values reported have not been adequately validated with performance data (Von Quintus et al. 2007). These studies indicate that there is a need to gain more information on the performance of this technique to significantly increase its use as a viable rehabilitation strategy.

The primary objective of this study is to evaluate the structural condition of existing rubblized concrete pavements across Iowa and to develop a knowledge database for rubblization, which will be useful in the selection of cost-effective PCC pavement rehabilitation strategies in Iowa. Seven representative rubblized concrete pavement sections across Iowa were selected for evaluation considering state wide location and pavement age. A series of field experiments were carried out at the selected test sections during 2007. The methodology and the results of data analysis are discussed in this paper highlighting the important findings regarding the long-term performance of Iowa rubblized concrete pavements.

## **RUBBLIZATION EXPERIENCE IN IOWA**

Iowa has a significant portion of PCC pavements in state highways and county roadways. Many of these pavements have deteriorated to a condition that requires rehabilitation or reconstruction. As early as 1985, the Iowa DOT recognized the potential of rubblization in rehabilitating old concrete pavements and conducted a research project to rehabilitate and evaluate a severely deteriorated concrete roadway (Tymkowicz and DeVrie 1995). A 3.0 km (1.9 mi.) section of L-63 in Mills county was selected and divided into 16 sections. In 1985, HMA overlay construction was done in 13 sections after rubblizing the existing pavement and in three sections without rubblization. The variables of rubblization, drainage, and HMA overlay depths of 75 mm (3 in.), 100 mm (4 in.), and 125 mm (5 in.) were evaluated in 1995. This research led to the following conclusions (Tymkowicz and DeVrie 1995):

- The rubblization process prevents reflective cracking.
- Edge drains improved the structural rating of the rubblized roadway.
- A HMA overlay of 125 mm (5 in.) on a rubblized base provided an excellent roadway regardless of soil and drainage conditions.
- A HMA overlay of 75 mm (3 in.) on a rubblized base can provide a good roadway if the soil structure below the rubblized base is stable and well drained.
- The Road Rater structural ratings of the rubblized test sections for this project are comparable to the non-rubblized test sections.

After this research, the use of rubblization has steadily increased in Iowa state highways and county roadways. Data collected during 2003 and 2004 from projects rubblized between 1997 and 2003 indicate a total of 21 rubblization projects in Iowa.

However, there were some changes in the rubblization practices adopted in Iowa which are due to poor subgrade, lack of crushed aggregate base, and the use of thin concrete pavements (Jansen 2006). The main keys to modified rubblization procedure include keeping the concrete pieces in place and tightly interlocked, achieving a maximum sizing in the 305 to 457 mm (12 to 18 in) range, and keeping traffic off the rubblized pavement until a lift of binder is down (Jansen 2006).

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## EXPERIMENTAL DATA COLLECTIONS

A field experiment was carried out from July 2007 to November 2007 to assess the structural condition of existing rubblized concrete pavements across Iowa. During the field testing, weather was sunny and roads were dried. Seven representative rubblized concrete pavements sections (listed in Table 1) were selected considering state wide location and pavement age. These pavements were at least 5 years old since the day of construction. The experimental test methods include the Falling Weight Deflectometer (FWD), the Dynamic Cone Penetrometer (DCP) and visual distress surveys. Core samples were also extracted to collect in-situ material, identify the layer underneath HMA layer, and provide space for conducting the DCP test. FWD and DCP tests and coring were performed on three locations in each test section – start (A), middle (B), and end (C) point. The visual distress survey was conducted on the entire test section.

Table 1. List of rubblized pavement sites for field evaluation

Test Section No.	Location		Layer Thickness (mm)			AADT*	Construction Year
	County	Road	HMA	Granular	Rubblized PCC		
1	Black Hawk	D16	168	0	191	1,280	2001
2	Black Hawk	V43	163	0	201	1,340	2001
3	Delaware	IA 3	246	0	221	740	2003
4	Franklin	C23	191	76	234	120	1998
5	Mills	L55	180	0	155	820	1999
6	Polk	IA 141	193	0	229	18,000	2001
7	Polk	IA 141	234	0	249	18,000	2001

\*AADT = Annual Average Daily Traffic in 2005

### *Falling Weight Deflectometer (FWD)*

FWD has become the standard equipment for evaluating the structural condition of a pavement structure due to the accuracy with which it can measure the deflected shape of a loaded pavement at appropriate rates of loading. The FWD test is conducted by applying dynamic (impulse) loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. The response of the pavement system is measured in terms of vertical deformation or deflection over a given area using seismometers (geophones). In this research, the FWD was used as the main Nondestructive test (NDT) equipment to evaluate the structural condition of rubblized pavement sections. Deflection data were collected using Iowa DOT's JILS-20 FWD (see Figure 1) by applying a step loading sequence of 27, 40, 53, and 67 kN (6,000, 9,000, 12,000 and 15,000 lbs) at three different locations (start, middle, and end point) in each test project. The locations of geophones in the Iowa DOT's FWD equipment are at 0 ( $D_{0mm}$ ), 203 ( $D_{203mm}$ ), 305 ( $D_{305mm}$ ), 457 ( $D_{457mm}$ ), 610 ( $D_{610mm}$ ), 914 ( $D_{914mm}$ ), 1219 ( $D_{1219mm}$ ), and 1524 mm ( $D_{1524mm}$ ) from the center of FWD plate load.



Figure 1. Picture of Iowa DOT's JILS-20 FWD equipment.

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**Dynamic Cone Penetrometer (DCP)**

DCP tests were conducted at the same locations after coring where FWD tests were conducted. The DCP tests were conducted to collect additional information about the in-situ subgrade soil properties. The DCP is an in situ device where measurements of penetration per blow (mm/blow) are obtained. In 2003, the ASTM published a standard for use of the DCP (ASTM D6951 2003), "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications." The device works by using a standard 8 kg (17.6 pound) hammer, which is lifted to the handle and dropped to the anvil, forcing the rod to penetrate the compacted soil area. The greater the number of blows needed to penetrate the rod into the soil, the stiffer the material.

**Visual distress survey**

Visual distress surveys over the entire test section were conducted for the selected project sites identified in the field evaluation program. The distress survey methodology employed was similar to that described in the Strategic Highway Research Program's (SHRP) "Distress Identification Manual for the Long-Term Pavement Performance (LTPP) Project" (Miller and Bellinger 2003). A distinction was made between reflective cracking and low -temperature (transverse) cracking. Cracking was identified as "reflective cracking" when the transverse cracks were uniformly spaced (corresponding to PCC joint spacing underneath the HMA layer).

**ANALYSES OF IOWA'S RUBBLIZED PAVEMENTS**

**FWD data analyses**

Two-frequency FWD tests were conducted on a single location to identify the FWD sensor measurement errors. No significant differences were observed, which indicated that the FWD can produce consistent results for same test material.

The measured deflections on geophones showed a linear trend with increasing FWD loads (see Figure 2). This indicates that the deflections at different FWD load levels can be normalized to one FWD load level. The measured deflections at 27, 53, and 67 kN of FWD loads were all normalized to 40 kN FWD load. Figure 3 presents the average of normalized maximum FWD deflections ( $D_{0mm}$ ) for each test section.

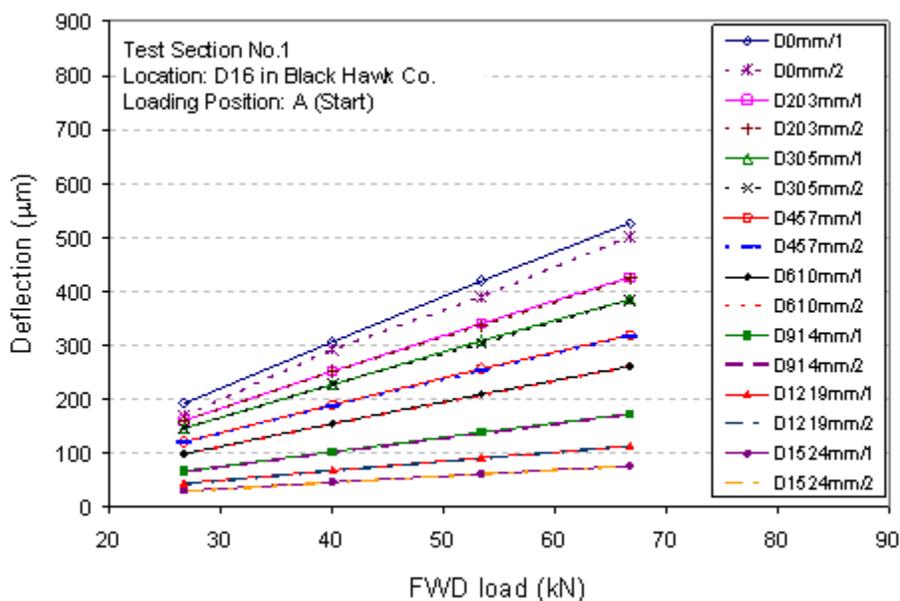


Figure 2. FWD deflections with loads.

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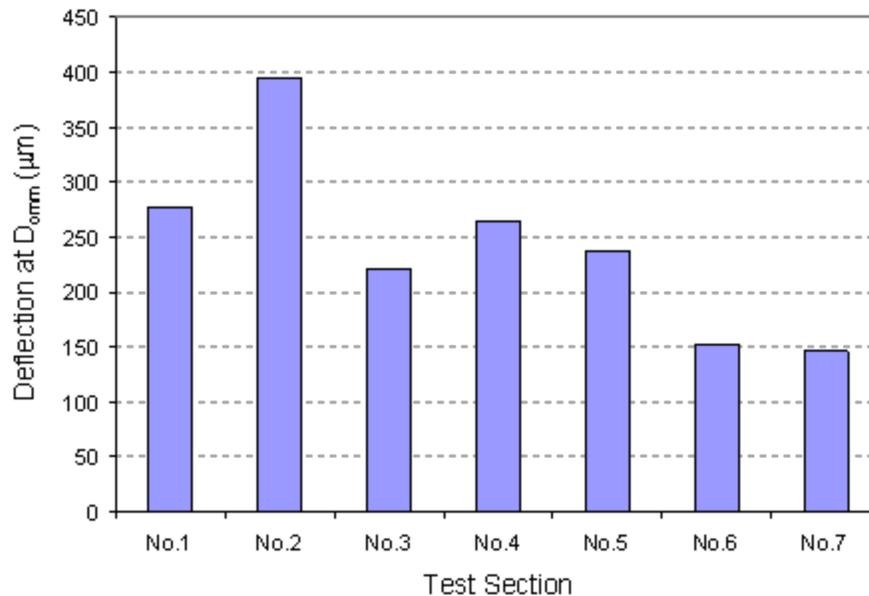


Figure 3. Normalized FWD maximum deflections ( $D_{0mm}$ ).

The pavement layer modulus is an important property representative of the pavement structural condition as well as a required input in the MEPDG. Recently, researchers at Iowa State University (ISU) developed a user-friendly, spreadsheet-based software for layer moduli backcalculation of rubblized PCC pavements (see Figure 4). This program employs Artificial Neural Networks (ANN)-based structural models for predicting not only the moduli of pavement layers based on FWD deflection data, but also the critical structural responses. The ANN-based structural models were developed by relating the structural responses (strains and deflections) to layer thicknesses and moduli values using a synthetic database. A synthetic database was generated using an Elastic Layer Program (ELP) by computing the critical strains for a wide range of layer thicknesses and moduli values. Details of the development and validation of ANN based structural models are described by Ceylan and Gopalakrishnan (2007).



Figure 4. ISU rubblized PCC pavement layer moduli backcalculation program.

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The FWD surface deflections obtained for rubblized sections were inputted into the ISU rubblized pavement layer moduli backcalculation program to predict the moduli of HMA, rubblized PCC and subgrade. The modulus of HMA is more temperature-sensitive than the modulus of rubblized PCC and subgrade. The computed HMA moduli at different temperature conditions were adjusted to the HMA moduli at a reference temperature (25 °C) using Eq. (1) reported by Nouredin (1994).

$$E_{AC} = E_{AC,25} \times \frac{2747.5}{(T)^{2.46}} \quad (1)$$

with  $E_{AC}$  = Asphalt concrete modulus (MPa),  $E_{AC,25}$  = Asphalt concrete modulus at 25 °C, and  $T$  = Asphalt concrete temperature, °C

Figure 5 clearly illustrates the effect of temperature on HMA modulus. The backcalculated HMA modulus below 25 °C decrease and the modulus above 25 °C increase after adjustment to the reference temperature of 25 °C.

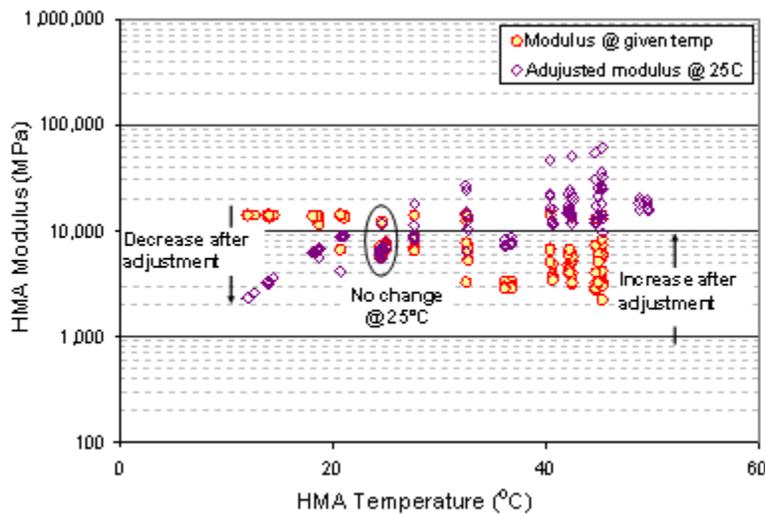
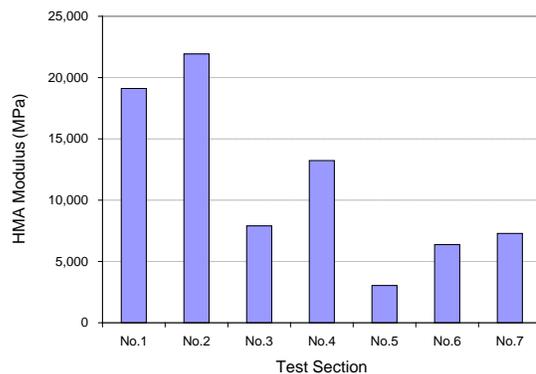


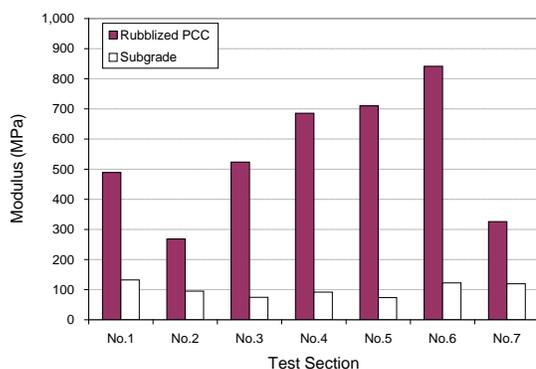
Figure 5. HMA moduli before and after adjustment to a reference temperature of 25 °C.

Figure 6 summarizes the layer moduli results for each of the rubblized sections. Table 2 presents the overall statistical summary for layer moduli results. The average rubblized PCC modulus in this study was found to be 539 MPa (78 ksi). This is numerically closer to the modulus value of 448 MPa (65 ksi) recommended by Wisconsin DOT study (Von Quintus et al. 2007). Both of them are lower than the default modulus value of 1034 MPa (150 ksi), which is currently used in MEPDG (NCHRP 2004) and recognized as a quite conservative value (Von Quintus et al. 2007). The backcalculated rubblized PCC modulus values in this study ranged from 259 to 1,120 MPa (38 to 162 ksi). This variation might be due to factors such as the condition of the existing PCC pavement, type and level of distress, type of construction equipment, environmental conditions, traffic, and type and thickness of HMA overlay. A similar range of values, 247 to 827 MPa (35 to 120 ksi), was reported by Wisconsin DOT study (Von Quintus et al. 2007). These values are similar to those determined from deflection basin testing of HMA overlays placed over rubblized PCC pavements – both from the Long-Term Pavement Performance (LTPP) Specific Pavement Studies-6 (SPS-6) experiment and actual construction projects reported by Von Quintus et al. (2000).

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(a)



(b)

Figure 6. Backcalculated pavement layer moduli: (a) HMA; (b) Rubblized PCC and subgrade.

Table 2. Overall statistical summary for pavement layer moduli

Variable	HMA Modulus (MPa)	Rubblized PCC Modulus (MPa)	Subgrade Modulus (MPa)
Average	12,092	539	100
S.D.	9,604	310	28
Max	60,416	1,120	140
Min	2,268	259	66

### DCP test results.

To represent DCP measures at different depths in each location, the average rate of penetration or penetration index ( $DCPI_{wtag}$ ) is determined by calculating the weighted average using the following Eq. (2) (Sawangsurriya and Edil 2004):

$$DCPI_{wtag} = \frac{1}{H} \sum_i^N [(DCPI)_i \times (z)_i] \quad (2)$$

with  $H$  = total penetration depth,  $z$  = layer thickness,  $DCPI$  = penetration index for  $z$ , (mm/blow)

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The rate of penetration (DCPI) has been correlated to the California Bearing Ratio (CBR, percent), an *in situ* strength parameter (ASTM D6951 2003). The DCPI-CBR correlation for soils other than CL soils below CBR 10% and CH soils is as follows:

$$CBR = \frac{292}{DCPI^{1.12}} \quad (3)$$

The CBR has been correlated to the resilient modulus ( $M_r$ ), an input parameter representing soil material strength in MEPDG (NCHRP 2004). The  $M_r$ -CBR correlation used in the MEPDG is as follows:

$$M_r = 2555(CBR)^{0.64} \quad (4)$$

The average  $DCPI_{wtag}$  and CBR values for test sections are 26.2 mm/blow and 15.9%, respectively. As shown in Figure 7, the average subgrade modulus value of 89 MPa (12ksi) obtained from DCP test results is slightly lower than the backcalculated subgrade modulus value of 100 MPa (14 ksi) obtained from FWD data using the ISU ANN-based backcalculation program. This result indicates that the ISU ANN-based backcalculation program provides good predictions for subgrade modulus.

The average rubblized pavement subgrade modulus value of 89 and 100 MPa (12 and 14 ksi) meets the minimum strength requirement 69 MPa (10 ksi) of the foundation layers for rubblization project specified by Wisconsin DOT (2007). Considering the fact that the DCP and FWD tests were conducted in summer, the results seem to indicate that the foundation layer of Iowa rubblized sections can provide enough strength.

### Visual Distress Survey

The visual distress survey results are summarized in Table 3. In general, no load-associated distresses, such as fatigue cracking, were found in any of the test sections as shown in Figure 8. The predominant distresses observed in the rubblized PCC sections are longitudinal cracking and low-temperature cracking as shown in Figures 9 and 10, respectively. No reflection cracking was observed in these rubblized PCC sections. The test sections were also well drained. These results tend to indicate that the rubblized pavement sections in Iowa are performing very well under the structural conditions identified in this study.

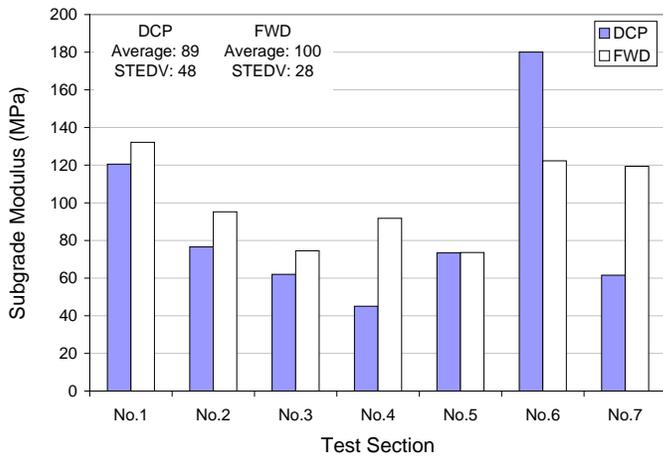


Figure 7. Comparison of subgrade modulus values from DCP and FWD.

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Table 3. Summary of visual distress survey results

Test Section No.	Location		Visual Distress Survey Results
	County	Road	
1	Black Hawk	D16	11 low temperature cracks
2	Black Hawk	V43	1 block and 8 low temperature cracks
3	Delaware	IA 3	2 longitudinal cracking on wheel paths (about 4.8 km) and 9 low temperature cracks
4	Franklin	C23	No cracks
5	Mills	L55	14 low temperature cracks
6	Polk	IA 141	14 longitudinal cracks, 3 low temperature cracks
7	Polk	IA 141	2 longitudinal cracks



Figure 8. Picture of distress-free HMA surface on rubblized PCC (test section no. 4: C23 in Franklin county).



Figure 9. Picture of longitudinal cracking on HMA overlaid rubblized PCC (test section no. 3: IA3 in Delaware county).

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Figure 10. Picture of low-temperature cracking on HMA overlaid rubblized PCC (test section no. 1: D16 in Blackhawk county).

## SUMMARY OF FINDINGS

The structural condition of existing rubblized concrete pavements across Iowa was evaluated through Falling Weight Deflectometer (FWD) tests, Dynamic Cone Penetrometer (DCP) tests, and visual pavement distress surveys, etc. Through backcalculation of FWD deflection data using the ISU layer moduli backcalculation program, the pavement layer moduli values were determined for various projects and were correlated with the long-term pavement performance. The backcalculated subgrade modulus values were also compared to the subgrade modulus values obtained from DCP test results. Based on the results of this study, the following findings and conclusions were drawn:

- Rubblization is a valid option to use in the rehabilitation of PCC in Iowa under good support or foundation.
- Iowa's rubblized pavement sections considered in this study are performing very well. The predominant distresses exhibited on HMA overlaid rubblized PCC sections are non-load associated distresses such as low-temperature cracking and/or longitudinal cracking.
- The average rubberized PCC modulus of the rubblized layer in this study was found to be 539 MPa which is close to the modulus value of 448 Mpa recommended by Wisconsin DOT study
- The ISU ANN-based backcalculation program provides good predictions for subgrade modulus.

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