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EVALUATION OF RUBBLIZATION PROECTS IN OHIO

FINAL REPORT

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16. Abstract:

This study was initiated to systematically analyze the performance characteristics of ODOT's completed rubblization and roll (R/R) projects and to develop guidelines regarding improved specifications.

The study was conducted in three parts namely, (i) performance evaluation of Ohio's R/R projects, (ii) overview of national perspective, and (iii) field demonstration of pavement breakers. The performance data obtained in terms of Pavement condition Rating (PCR) was processed to objectively analyze the effectiveness of rubblization on the functional condition of the constructed pavements. The Falling Weight Deflectometer (FWD) data was collected and analyzed to compare the structural conditions of the R/R pavements. Data was collected from other state DOTs to register the performance of their R/R pavements and to learn of their experience with R/R projects. Finally, a 1-day field demonstration of rubblization was conducted to demonstrate the capabilities of pavement breakers operating in Ohio to rubblize under identical conditions. This task was of particular value to verify the compliance of pavement breakers with ODOT specification 320.

The study led to the following primary conclusions:

- R/R is an effective concrete and composite pavement rehabilitation technique. Results show an overall improvement in pavement performance.
- The performance period of surface layer of R/R pavements is estimated to be 11.7 years.
- The application of preventive maintenance treatment, depending on the type used in Ohio, extends the performance period of the constructed pavement; thereby implying consecutive application of PM treatments will result in R/R pavements achieving or exceeding a design life of 20 years.
- Rubblization contributes to significant changes in structural condition; the process transforms the rigid concrete layer into a flexible base.
- Lately, there are several variants of MHB. ODOT should change the equipment specification to allow other variants of MHBs.
- There is no adequate data available to relate fragment size to performance. However, based on the data from the demonstration study, it is inferred that ODOT should change the fragment specification to allow up to 12" fragments.
- ODOT's quality control/quality assurance procedure requires digging a test pit at the beginning of the project to investigate the size and shape of fragments. This procedure is not consistently applied in all projects. ODOT would benefit by adopting a more stringent QC/QA procedure.
- It is important to revise ODOT's policy regarding the criteria for the selection of candidate projects for rubblization and validate the threshold value established.

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- Antigo Construction Inc., Antigo, Wisconsin
- Specialties Company LLC, Indianapolis, Indiana
- Wagway Tool Company, Indiana
- The Jurgensen Companies, Cincinnati, Ohio

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1. GENERAL

Rubblization is a process of breaking existing concrete pavement into small fragments using heavy duty pavement breakers. Rubblization is intended to transform the exposed concrete pavement into crushed base layer. Generally, within 24 hours, the rubblized layer is rolled using a heavy roller and covered by an asphalt concrete (AC) overlay. The purpose of rubblization of concrete pavements before constructing AC is to obliterate reflection cracking in composite pavements.

This report presents the details of a study conducted to evaluate the long term performance of AC overlays on rubblized and rolled (R/R) concrete pavements constructed by the Ohio Department of Transportation (ODOT). The primary goal of the study is to evaluate effectiveness of rubblizing concrete pavements as a rehabilitation strategy for improving the overall pavement performance. The fundamental issues considered in the study include the following:

1. What is the effect of rubblization on the functional condition of the pavement?
2. What is the effect of rubblization of the structural integrity of the pavement?
3. Does the type of pavement breaker have an impact on the resulting pavement performance?
4. How does ODOT's fragment size specification compare with other DOTs?
5. Is there an established criterion for selecting candidate projects for R/R?
6. What changes are needed to the ODOT's current R/R specification?
7. In general, what can this research do to benefit ODOT?

1.1 Incidence of Reflection Cracking

Reflection cracks are primarily caused by tensile stresses in the asphalt layer which are induced by the expansion and contraction of the underlying Portland Cement Concrete (PCC) pavement in response to temperature changes. The cracks form at the bottom of the asphalt layer, above a joint or a crack, and propagate vertically to the surface. These reflection cracks -- which begin as a pattern of narrow, difficult-to-seal cracks that mirror the joints and cracks in the underlying concrete pavement – permit water to enter the pavement, triggering early deterioration of the overlay, increase in life-cycle costs and a reduction in the useful life of the pavement. An illustration of the development and propagation of reflection cracking is presented in Figures 1 and 2.

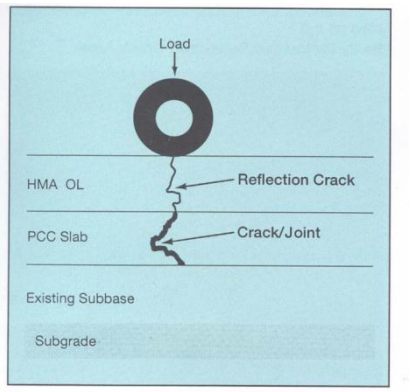

Figure 1 Schematic of Reflection Cracking [1]

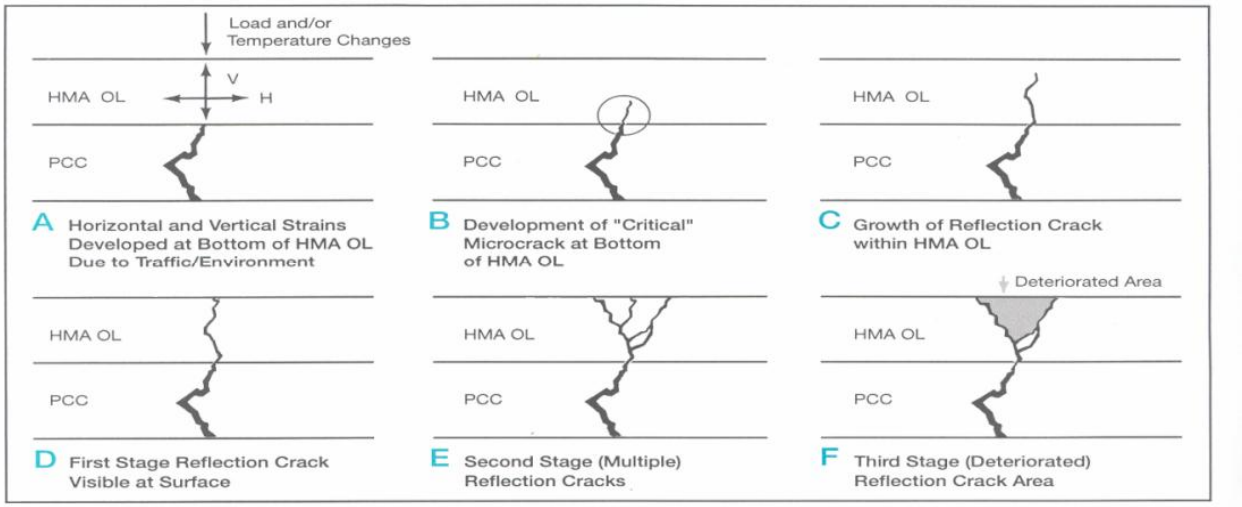

Figure 2 Growth of Reflection Cracks [1]

Reflection cracking can also result from shear stresses created by differential deflection between the approach and leave slabs. In either case, when the stress exceeds the strength of the asphalt overlay, a crack begins and eventually propagates to the surface. Figure 3 shows examples of reflection cracking in composite pavements.

Figure 3 Typical Reflection Cracking in Composite Pavements

1.2 Mechanism of Reflection Cracking

The extent of thermal movements in concrete slabs that cause expansion and contraction of the PCC pavement can be illustrated using the following equation:

$$\Delta L = \propto * \Delta T * L$$

where: ΔL = thermal movement (change in length), α = coefficient of thermal expansion of concrete, ΔT = change in temperature, and L= length of concrete slab.

During winter months, when there is a drop in temperature by ΔT, the concrete slabs will undergo contraction and the joints will move away from each other. This movement will exert horizontal tensile stress on the overlying AC layer which is perfectly bonded to the concrete slabs. With α being a constant characteristic of the material, for a given ΔT it can be deduced the extent of thermal movement ΔL is directly proportional to L, the original length of the slab. This implies the shorter the length of the slab, the smaller the movement at the joint. Minimizing such movements should improve the chance of reducing crack development and in turn reflection cracking. This phenomenon is illustrated in Figure 4.

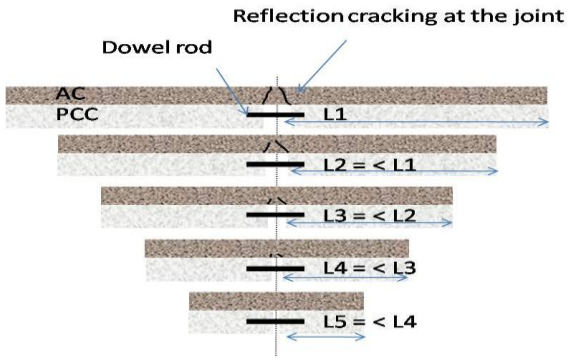

Figure 4 Effect of Length of Concrete Slab on Joint Reflection Cracking

1.3 Proposed Solutions

Over the years, a wide variety of techniques have been proposed to eliminate, delay, or lessen the severity of the reflection cracking problem. These include the use of bond breakers, reinforcement in the overlay, stress-absorbing membranes and interlayers, waterproofing treatments, stronger and thicker overlays, and saw-and-seal procedures. These solutions yielded mixed success and/or inconclusive results.

1.4 Fractured Slab Techniques

For twenty years or more, an increasing number of state DOTs have routinely or experimentally used a family of "fractured slab techniques" to provide a cost-effective solution to the reflection cracking problem. The fractured slab techniques include Crack and Seat (C/S), Break and Seat (B/S) and, Rubblize and Roll (R/R). Each of these procedures shares a common premise: fracturing concrete pavement prior to overlay will reduce slab action and thereby minimize thermal movements to such an extent reflection cracking of the overlay is prevented, delayed, or reduced in severity and extent.

For non-reinforced plain jointed concrete pavements, "cracking and seating" may be sufficient to decrease the effective slab size of the concrete so as to reduce the opportunity for reflection cracking. For reinforced concrete pavements, cracking is often not sufficient; the amount of fracturing energy applied to the pavement must be sufficient to "break" both the bond to the steel and the concrete. As the name implies, the "rubblizing" alternative carries the fracturing process to the extreme: complete destruction of the concrete slab and all concrete slab action. The rubblizing process effectively reduces the existing slab to an in-place crushed aggregate base. Since the existing pavement distresses and joints are obliterated, rubblizing is

reported to be the most effective of the fractured slab techniques in preventing reflection cracking. The three fracturing techniques are distinguished primarily on the basis of the specified range of size of the fractured particles.

1.5 Influence of Fragment Size on the Overlay Thickness

For the pavement designer, determining the appropriate fracturing technique and/or particle size for a particular distressed concrete pavement involves striking an economical balance between two performance extremes:

- No fracturing or insufficient fracturing of a concrete pavement prior to overlay will provide a strong base for paving, thereby requiring a relatively thin overlay, but one which--on account of its stiffness--is highly susceptible to reflection cracking and consequent reduced performance period.
- Excessive fracturing will drastically reduce the stiffness of the concrete, which eliminates the potential for reflection cracking, but which provides a weaker base for paving, requiring a thicker overlay to compensate for the loss of support.

Recently, there is an apparent trend among departments of transportation to permit considerably larger maximum size particles near the surface: up to 12 to 18". This practice referred to as "Coarse Rubblization", is intended to promote constructability and provide cost savings [2]. This approach to optimizing fractured particle size is shown graphically in Figure 5 [3].

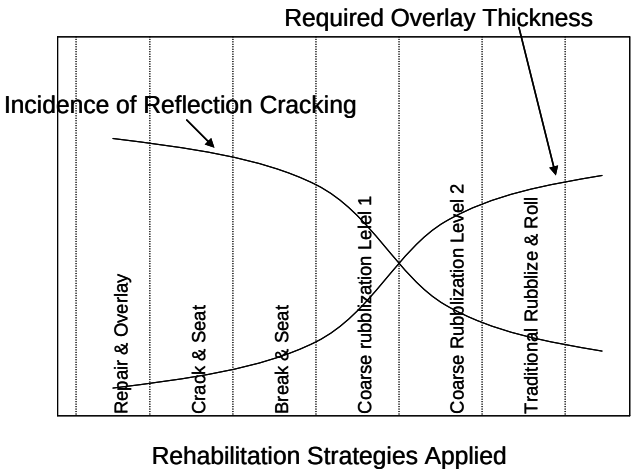

Figure 5 Conceptual Illustration of Consequences of Varying Breaking Pattern

1.6 Preventive Maintenance, Design Life, and Performance Period of R/R Pavements

From a pavement management perspective, it is necessary to ensure pavements are maintained such that they provide a minimum level of service during their design life. By and large, there are three groups of maintenance treatment activities: preventive, routine, and reactive maintenance. A preventive maintenance (PM) is a strategic treatment applied to an existing pavement to retard future deterioration and to maintain or improve the functional condition of the system without significantly increasing its structural capacity. In other words, the purpose of preventive maintenance treatment(s) is to facilitate in accomplishing the "design life" of a pavement.

Under ODOT'S pavement preservation policy, PM treatments such as micro-surfacing, thin-AC overlay, chip seal, crack seal are generally applied after about 12 years of either new construction or major rehabilitation of pavements. The application of PM treatment(s) is triggered at the end of the "performance period of the surface course" of a pavement in order to enhance pavement performance, ensure cost-effectiveness, and reduce user delays during a

"design life" of a pavement. Because of its relevance, it is essential to discern between pavement "performance period" and pavement "design life" as used in this document. Figure 6 illustrates "design life" and "performance period" of pavements.

Design Life: This term is used to define the number of years between successive major rehabilitations, exclusive of any additional life provided by anticipated preventive maintenance during the design period.

Performance Period: This is the term used to define the number of years between a major rehabilitation and preventive maintenance treatment or between successive preventive maintenance treatment(s).

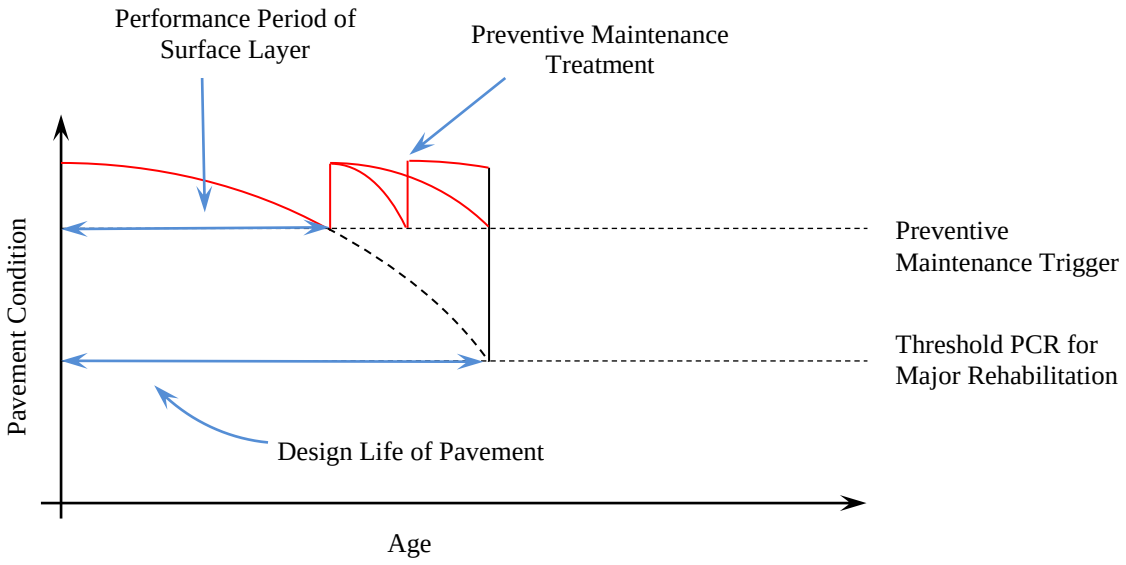

Figure 6 Design Life and Performance Period of Pavements

2. PRESENT STUDY – OBJECTIVES AND SCOPE

Based on continuing reports of the successful use of the R/R technique by other states [1, 2] and the potential for long-term cost savings [4], ODOT has begun to increasingly focus on R/R as the preferred methodology for eliminating reflection cracking in asphalt overlays of reinforced concrete pavements. A list of Ohio's R/R projects is shown in Table 1.

The **first objective** of the study was to evaluate the overall performance of AC overlays on R/R pavements using the data from Ohio's projects.

As can be seen in the table, since 1988 ODOT has used the rubblization technique on twenty seven concrete pavement rehabilitation projects involving more than two million square yards. Two types of pavement breakers namely, Resonant Pavement Breaker (RPB) and Multiple Head Breaker (MHB) were used in these projects. Over the first ten years, the pre-overlay pavement fracturing on all ODOT projects was performed exclusively with a RPB. Beginning in 1998, MHB came into use on ODOT projects. Figure 7 shows the extent of rubblization done in Ohio along with a breakdown of work performed by three pavement breakers.

Table 1. Ohio's R/R Projects [5]

Construction Year	County	Route	Blog	Elog	Length	Breaker Type	PCC
1988	LIC	70	28.93	29.42	0.49	RPB	8" CRCP
1988	MUS	70	0.76	5.7	4.94	RPB	8" CRCP
1990	LIC	16 EB	28.07	29.28	1.21	RPB	9" JRCP
1990	LIC	16 EB	29.28	31.27	1.99	RPB	7" CRCP
1990	LIC	16 WB	28.07	33.14	5.07	RPB	7" CRCP
1990	MUS	16 EB	0	0.2	0.2	RPB	7" CRCP
1990	GAL	35 WB	1.03	3.5	2.47	RPB	9" JRCP
1991	LUC	20 NB	16.62	16.96	0.34	RPB	9" JRCP
1993	ROS	23 NB	9.38	10	0.62	RPB	9" JRCP
1994	FAI	33	0	12.58	12.58	RPB	9" JRCP
1995	LIC	70	15.96	23.84	7.88	RPB	9" JRCP

Construction Year	County	Route	Blog	Elog	Length	Breaker Type	PCC
1995	BEL	70	0	5.04	5.04	RPB	9” JRCP
1997	COS	36	20.83	22.56	1.73	RPB	9" JRCP
1998	COS	36	22.56	27.75	5.19	RPB	9" JRCP
1997	COL	7	4.67	5.48	0.81	RPB	8" CRCP
1998	COL	14F	1.7	1.82	0.12	MHB Badger Breaker	8" CRCP
1998	COL	62	13.01	14.09	1.08	MHB Badger Breaker	8" CRCP
1999	GRE	CR99	0.85	3.3	2.45	MHB Badger Breaker	7" JRCP
2000	MED	271	0	6.58	6.58	MHB Badger Breaker	10" JRCP
2000	SUM	271	0	2.24	2.24	MHB Badger Breaker	10" JRCP
2000	GRE	35J	0	4.67	4.67	MHB Badger Breaker	8" CRCP
2000	STA	77	11.68	12.68	1	MHB Badger Breaker	10" JRCP
2001	TUS	77	3.94	7.55	3.61	MHB Badger Breaker	9" JRCP
2002	TUS	77	7.55	12.3	4.75	MHB Specialties	9" JRCP
2004	CLA	70	25.45	28.95	3.5	MHB Specialties	8"CRC
2005	FAI	33	12.58	13.74	1.16	MHB Specialties	9" JRCP
2006	HAM	275	22.8	28.25	5.45	MHB Specialties	10" JRCP
2008	BUT	75	3.76	11.25	7.49	MHB Specialties	9” JRCP
2008	WAR	75	0	3.4	3.4	MHB Specialties	9” JRCP

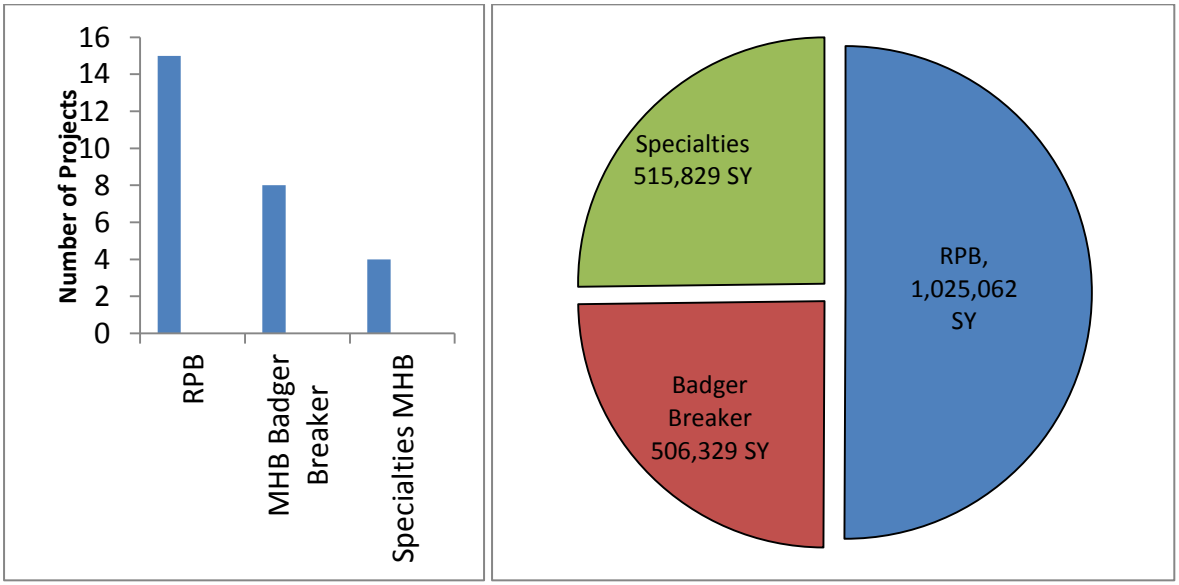

Figure 7 Pavement Breakers - Number of Projects and Area of Pavement Rubblized

The **second objective** of this study was to investigate, with the aid of performance data from the R/R sections constructed in Ohio, if all the pavement breakers are capable of consistently producing the controlled breaking patterns and fractured particle sizes specified by ODOT.

ODOT's R/R specification requires majority of the concrete slabs to be broken into 1 to 2" and no particle to exceed 6". In Ohio, the construction cost of a pavement rehabilitated with R/R process is significantly higher than one rehabilitated with break and seat. In the first place, the required overlay thickness on an Ohio rubblized pavement (structural coefficient 0.14) is much thicker than on a B/S pavement (structural coefficient 0.27). Added to that is the greater incremental cost of the fracturing process: the cost of rubblization is typically about 3 to 4 times that of breaking and seating. However, based on literature reports [6, 7, 8] of success with Coarse Rubblization, it seems possible to determine an *optimum* maximum particle size – larger than the conventional maximum for rubblization, but smaller than that for B/S – which would reduce the required thickness of the overlay, while still minimizing the potential for reflection cracking. If so, this could provide a breakthrough in providing a cost-effective solution to Ohio's reflection cracking problem. Thus the **third objective** of this study is to determine, through a detailed review of literature, other states' rubblization specifications, design guidelines, and project performance to determine the best state-of-the-practice.

In Ohio, the selection of candidate projects for the R/R treatment is based on the subgrade soil strength as determined by the Standard Penetration Test (SPT). ODOT specification states that the R/R is not an option when the average SPT value of the existing pavement is below 15 [9]. This value was arrived at based on the experience with previous R/R projects and there is no physical data to justify the established threshold value. A **fourth objective** of this study is to

extract information from the literature and other state's practices for a rational procedure for the selection of candidate projects for the R/R procedure.

This report describes the details of the investigation including the following:

1. A comprehensive assessment of the performance of Ohio's rubblized pavements,
2. Analysis of influence of the type of pavement breaker,
3. Detailed review of R/R practices in other states,
4. Review of rubblization specifications in other states including the equipment used, fragment size requirements, and criteria, if available, for the selection of projects for R/R,
5. Guidelines regarding improved specifications for future R/R projects in Ohio.

3. ODOT's R/R SPECIFICATION

The size ranges traditionally required by ODOT for the various fractured slab techniques, are shown in Table 2.

Table 2. Fractured Pavement Particle Sizes Required by ODOT

Fracturing Technique	**Particle Size**	
	Predominant/Target	**Maximum**
Crack and Seat [10]	48" x 48"	60"
Break and Seat [11]	18"	30"
Rubblize and Roll [12]	1 to 2"	2" (above reinforcing steel), 6" (below reinforcing steel)

ODOT's R/R specification as outlined in Item 320 of the Ohio DOT Construction and Materials Specifications [12] highlights three items namely:

- Equipment,
- Construction, and
- Quality control and quality assurance

ODOT allows both resonant and multiple head type breakers to operate in Ohio. A careful look at the equipment description clearly indicates they relate to RPB and MHB, the two pavement breakers operating in the market when the specification was developed. Ohio's rubblization projects require a test section to be designated at the beginning of the project. The intent of the test site is to determine the striking energy and the pattern required through the project. This is a very important requirement as the energy requirement would depend on project specific conditions such as condition of concrete pavement and type and condition of subgrade soil. Obviously, such test sites should be established as and when there is a change in conditions. The striking energy should be sufficient to induce full depth cracking of the concrete pavement. A majority of the broken fragments are expected to be between 1" to 2" with no particle exceeding 6" in its largest dimension. In addition, breaking should also result in debonding of steel reinforcement. A test pit required at the beginning of the project serves as a measure of quality of rubblization. After rubblization, a vibratory steel roller is to be used to roll the broken fragments. Traffic is allowed only after placing an intermediate layer.

4. DESCRIPTION OF RPB AND MHB PAVEMENT BREAKERS

4.1 Resonant Pavement Breaker

The Resonant Pavement Breaker, developed in 1986 [13] -- also known as the Vibratory or Sonic Pavement Breaker – is reportedly the most widely-used type of equipment on rubblization projects. Several models of this equipment are available, varying in size and weight. The PB-4 model is widely used on highway projects (Figure 8).

Figure 8 Resonant Pavement Breaker

In this machine, a resonance is set up in a beam by a rotating eccentric weight. A shoe attached to the end of the beam rides along the pavement surface, striking the pavement with low amplitude (1/2 to 1 inch), high frequency impacts at the resonant frequency of the slab (about 44 Hz), causing the concrete to break apart. The vibrating shoe fractures the pavement in strips as the machine moves along the unfractured edge of the pavement. This vibrating beam has been

described as a giant tuning fork [14, 15]. Production rate is approximately one lane mile per day but will vary based on the strength and thickness of the slab and underlying subbase/subgrade. Performance claims made for the RPB equipment include:

- Complete debonding of the reinforced steel, which is a prerequisite to avoiding subsequent reflection cracking;
- An angular fracturing pattern that provides greater support (i.e., higher effective modulus) and thus permits thinner overlays to be used; and
- No damage to the base material (hence, better load distribution) because the energy from the low amplitude impacts is dissipated within the slab [13].

In using RPB, pavement fracturing operations can be conducted while maintaining traffic in adjoining lanes. However, because the RPB equipment can encroach on the adjoining lane at some stages of its multiple-pass operation, more extensive traffic controls may be required. Also, because one side of the 30-ton RPB machine travels on rubblized concrete during the fracturing operation, there is a potential for deformation of the underlying base course or subgrade in, e.g., areas of weak soil support or a high water table [16].

4.2 Multiple-Head Breaker

The Multi-Head Breaker came into use in 1997. This equipment uses a series of independently-controlled, high-amplitude drop hammers to fracture the slab (Figure 9). The first units were produced by the Badger State Highway Equipment, Inc.; a later variant is being produced by Specialties, Inc., an Indiana company.

Figure 9 Multi-Head Breaker

Typically, on the MHB, there are between 12 and 16 hammers, mounted in pairs in two rows ("heads"). The hammers in the rear row are offset from those in the forward row to provide continuous breakage from side to side. Each of the 8-inch wide hammers weighs between 450 – 680 kg (1000 – 1500 lbs). Hammers can be dropped from variable heights (1 to 5 feet) and cycle at a rate of 30 to 35 impacts per minute [17].

The MHB unit reportedly has two main advantages. First, it can rubblize a full lane width in a single pass at high production rates (up to 1.5 miles per day). This one-lane/one-pass operation not only can lead to reductions in the unit cost of the fracturing operation, but also helps avoid costly road closures and crossovers, and the associated disruptions of traffic. Secondly, the amount of fracturing energy transferred to the pavement during each impact can be adjusted within wide limits (2,000 to 12,000 foot-pounds) through adjustment of the drop height. This permits the operator to control the size of the fractured particles.

5. R/R – NATIONAL PERSPECIVE

Rubblization and rolling concrete pavements is being used by many state DOTs during the last 20 years as a major rehabilitation technique. A cursory view of the practices show R/R predominantly applied to jointed reinforced concrete pavements and occasionally to continuously reinforced concrete pavements. Key states that have constructed a number of R/R projects include Arkansas, Alabama, Illinois, Iowa, Kansas, Louisiana, Michigan, Nevada, New Jersey, New York, Ohio, Oregon, Pennsylvania, South Carolina, West Virginia, and Wisconsin [18]. Most states have observed good to excellent performance and consider R/R as a viable concrete pavement rehabilitation technique. Some of the benefits reported from R/R projects include elimination of reflection cracking, improved overall pavement performance, and decreased life cycle costs. For example, the economics of rubblization have led Arkansas, Michigan and Wisconsin DOTs to rubblize several million square yards of concrete pavements [19].

Alabama DOT [20] reported that R/R projects have proved to be effective and efficient means of rehabilitating in-service concrete pavements. Arkansas [21] has in the recent times made the most significant investment on R/R projects, exceeding $1.3 billion. Before embarking on rehabilitation of about 300 miles of in-service concrete pavements on I-40 in 2005, the DOT conducted a pilot study at two sites. The primary intent of the pilot study was to evaluate the performance of the two pavement breaker types namely, RPB and MHB. Based on field observation of the particle sizes and analysis of deflection data, leading to the modulus of rubblized layer, the state adopted RPB to rubblize the entire project. Utmost importance was given to drainage by Arkansas DOT. The initial reports indicate high level of serviceability. However, long-term monitoring is needed for a realistic evaluation of performance of the constructed pavements. Colorado and Indiana [22, 23] have allowed both RPB and MHB

pavement breakers in their R/R projects. Michigan was among the first states to adopt R/R practice [24]. All projects are reported to be performing well. Interestingly, Michigan DOT is one of the very few states to have established criteria for the selection of candidate projects for R/R. The state stipulates minimum resilient modulus of subbase (7ksi) and subgrade (3ksi) to be eligible for rubblization. Perhaps, New York [4] was the first state to introduce rubblization technique. The state has constructed several sections using both MHB and RPB breakers and reports increasingly good success with R/R projects. Pennsylvania [25, 26] constructed six sections using MHB and reported satisfactory performance after being in service for ten years. Texas [27] reported sporadic problems in breaking slabs and mixed performance of R/R pavements as a result. Wisconsin [28] is one of the leading states in the use of R/R technique. The state has constructed over 80 sections and conducted several studies, both in-house and contracted, to review (i) the performance of its own R/R pavements, (ii) performance of R/R sections in other states, and (iii) the prevailing R/R practices in other states. While Wisconsin R/R sections have performed very well, prior pavement conditions and the thickness of AC layer appear to have an impact on the pavement performance. The state regards R/R projects are cost effective, costing the state 25 to 50% less than other options.

A number of issues namely, the type of pavement breaker, extent of breaking, size of broken fragments, prior condition of concrete slabs, type and condition of base and subgrade, traffic and environmental conditions are known to influence the long-term performance and life-cycle costs of the rehabilitated pavements.

By closely monitoring of the performance of constructed pavements, these states conclude that overall, rubblization has been successful.

6. DATA GATHERING

For each of ODOT's R/R project, the following information was collected from ODOT's Pavement Management Information System (PMIS):

- Performance data in terms of Pavement Condition Rating (PCR)
- Deflection data using Falling Weight Defletometer (FWD), and
- Construction, maintenance and rehabilitation history.

In addition, data was collected about performance of R/R sections and experiences thus gained in other states through:

- Literature review, and
- Site visits to selected states.

Since 1985, ODOT has been collecting performance monitoring data annually on all of its pavements. One of the key elements of this process is the conduct of visual distress surveys, which involve observing and recording the extent and severity of individual surface distresses for various types of pavements. The data is converted into a numerical index on a 0 to 100 scale, termed Pavement Condition Rating (PCR) [29]. The collected performance data (PCR numbers, individual distress data), along with construction records, is stored in ODOT's PMIS. PCR data was extracted for all the sections starting from the year prior to rubblization and for each year thereon till the project was in service or another activity was performed.

On all the sections, deflection data using Falling Weight Deflectometer was collected and stored in separate files. On average, deflection data was collected at about 40 points in each mile.

The construction table from PMIS was used to extract the year of rubblization and follow-up maintenance and rehabilitation if any. Construction records were referred to deduce information like the type of pavement breaker used and other relevant details.

In addition, data from other states was compiled through literature review. The review provided a qualitative assessment of the R/R projects.

Particular attention was placed to determine if the performance can be related to size of fragments allowed in the specifications.

7. EFFECT OF RUBBLIZATION ON THE FUNCTIONAL CONDITION OF THE PAVEMENT

PCR was used to represent the functional condition of the pavement sections under review. To begin with, historic PCR data for 13 R/R sections was compiled along with the construction data. R/R sections that were constructed after 2004 and those that were reported to have received minor or major rehabilitation within four years after rubblization were not included in this analysis, because of insufficient performance data. Table 3 shows the number of years R/R sections have been in service and the follow-up treatments.

Table 3. Ohio's R/R Sections Used for Performance Investigation

Sl. No.	Section	# of years in service as R/R pavement	PCR of R/R pavement prior to follow-up treatment	Treatment following rubblization
1	BEL 70	8	90	Thin AC overlay without repairs
2	COS 36	5	79	Fine graded polymer AC overlay
3	FAI 33	8	87	Thin AC overlay without repairs
4	LIC 16	6	72	Thin AC overlay with repairs
5	LUC 20	11	72	Thin AC overlay without repairs
6	MUS 70	5	79	Double application of micro surfacing
7	COL 62	8	81	These sections continue to be R/R pavements
8	MED 271	6	94	
9	MUS 16	9	88	
10	SUM 271	6	91	
11	TUS 77	6	94	
12	ROS 23	9	91	
13	STA 77	6		

Out of the 13 R/R sections available in the database, six sections have received some form of maintenance and/or rehabilitation following rubblization. The PCR value of rubblized pavements prior to further treatment ranged considerably from 72 to 90. A description of performance history of the four rubblized sections can be made with the aid of Figure 10.

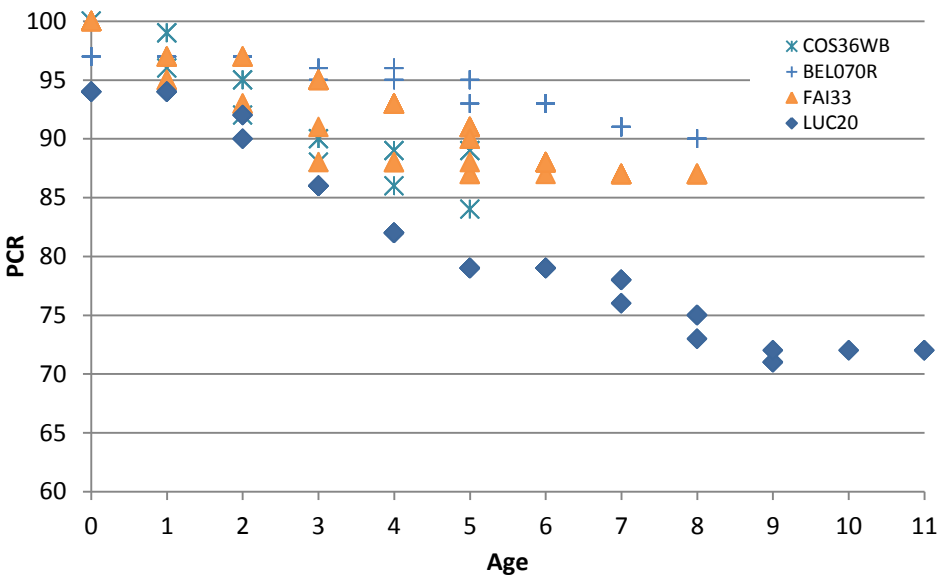

Figure 10 Pavement Performance of Individual Sections

Of the six sections that received a treatment following rubblization, BEL 70 has performed exceptionally well with its PCR staying at 90 after eight years of service, closely followed by FAI 33 whose PCR stayed at 87. Unlike the well performing BEL 70 and FAI 33 sections, the performance of COS 36, LIC 16 and MUS 70 sections has rapidly and consistently declined reaching PCR of 79, 72 and 79 respectively in a span of five to six years. A further review revealed that MUS 70 was under-designed and LIC 16 and STA 77 did not have sufficient performance data. As a result these two sections were disregarded from further analysis. It can also be observed LUC 20 section lasted for 11 years before reaching a PCR of 72.

The intent of the above discussion is to illustrate a general trend of the performance of R/R sections. However, performance data from all sections in Table 3 (excluding MUS 70, LIC 16, and STA 77) are considered to develop performance model as explained later in section 7.1. Figures 11, 12, and 13 show the general condition of selected R/R pavements prior to follow-up treatment.

Figure 11 Typical View of COS 36 Section

Figure 12 Typical View of LIC 16 Section

Figure 13 Typical View of MED 271 Section

In summary, variation has been noticed in the performance characteristics of R/R pavements, primarily in terms of the rate of deterioration. A review of the database indicated that, variables such as pavement type (Jointed Reinforced Concrete Pavement, Continuously Reinforced Concrete Pavement) and pavement breaker type may have contributed to the variation in performance of R/R pavements.

To investigate the effect of pavement breakers and type as well, PCR data from rubblized pavements indicated in Table 3 was used. The analysis included the following:

1. Development of pavement performance model for R/R sections combined (1 model);
2. Grouping the data according to the type of pavement breaker and development of performance models for each breaker type (2 models - one for RPB and one for MHB);
3. Grouping the data according to pavement type (2 models – one for JRCP and one for CRCP)

7.1 Performance Model for Rubblized Pavements

A performance model was developed using PCR data of R/R sections regardless of breaker type. A review of data revealed that adequate performance data was available for 10 out of 13 sections (COS62, MUS16, ROS23, COS36, BEL70, MED271, TUS77, SUM271, FAI33, LUC20). A total of 621 PCR values with corresponding pavement age were available to develop the models. The scatter plot and the performance model are shown in Figure 14. Several shape functions were attempted to fit the data. Eventually, a fourth degree polynomial equation with an R^2 value of 0.52 was found to fit the data reasonably well.

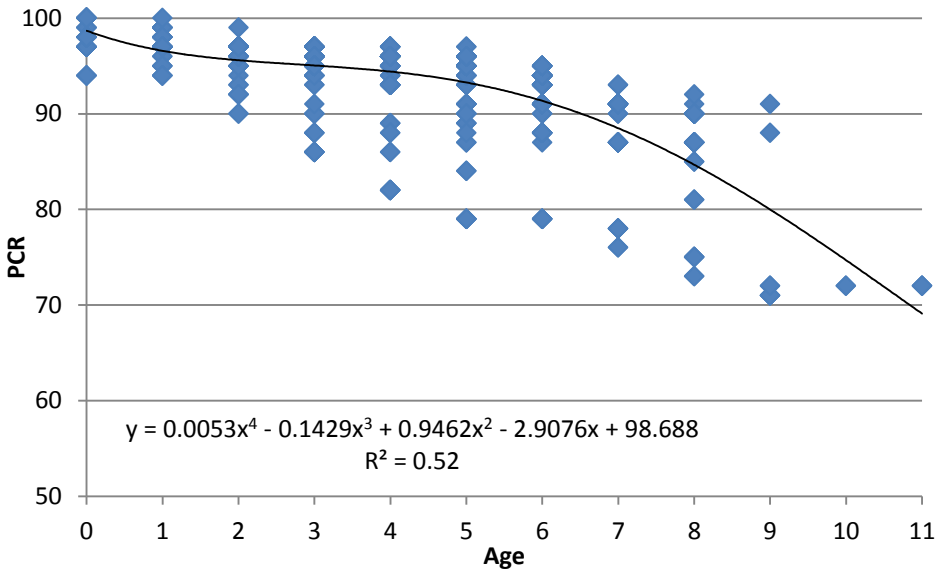

Figure 14 Pavement Performance Model – MHB and RPB Type

The model shows a logical trend with PCR decreasing gradually with time. An immediate use of the model can be to estimate the performance period of the surface course of R/R pavements. Since most of the R/R sections were constructed on Ohio's priority system highways, the above model was used to determine the performance period of surface course of

R/R pavements corresponding to PCR threshold 65 in compliance with ODOT's procedure. The performance period of surface course of Ohio's R/R sections was found to be 11.7 years.

7.2 Performance Model Based on Type of Pavement Breaker

The scatter plot of performance data for individual R/R sections is illustrated in Figure 15. This figure assists in identifying the performance of individual R/R sections, as opposed to Figure 13 which is a collection of all PCR data points.

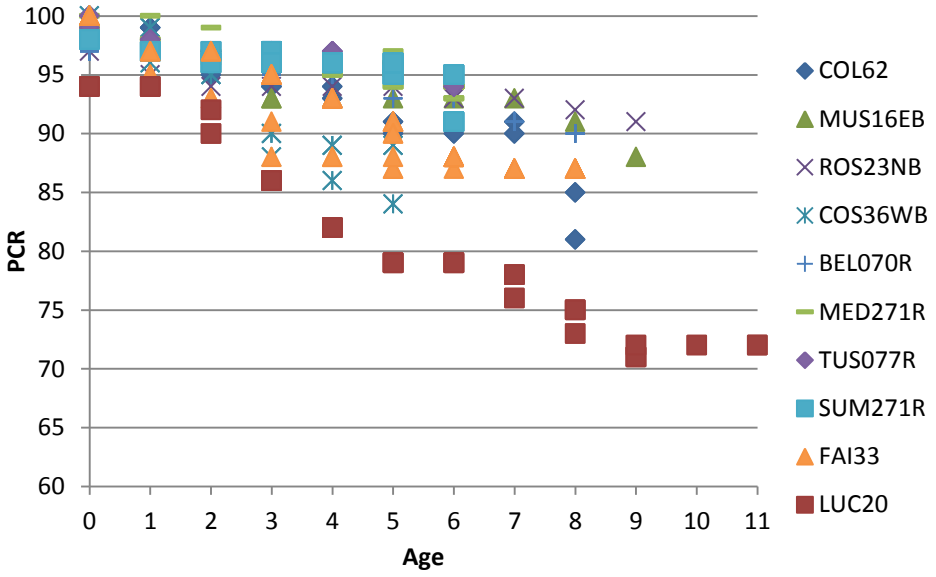

Figure 15 Pavement Performance of Individual Sections

The potential reason for this variation may be due to the different pavement breakers used. Therefore, to investigate the effect of pavement breaker type, the dataset was separated into two groups according to the pavement breaker type namely: a) Multi-head breaker and b) Resonant Pavement breaker. A total of 334 PCR points for MHB type and 287 points for RPB type for different sections became available for the analysis.

7.2.1 Performance Model for Pavements Rubblized Using MHB

Figure 16 shows the performance model for pavements rubblized using Multi-head breaker. A significant increase in R^2 (from 0.52 to 0.79) was observed, and this indicates uniformity in the performance characteristics of MHB sections. The individual sections used in the analysis are shown in Figure 17.

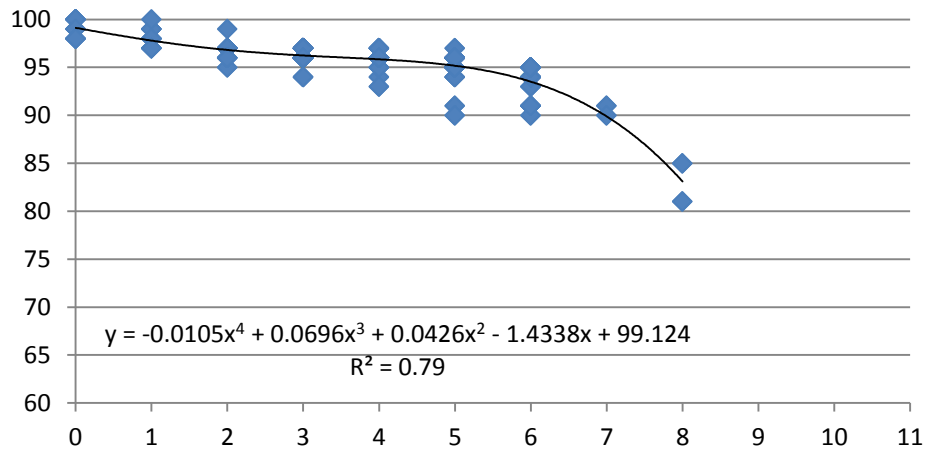

Figure 16 Pavement Performance Model – MHB Type

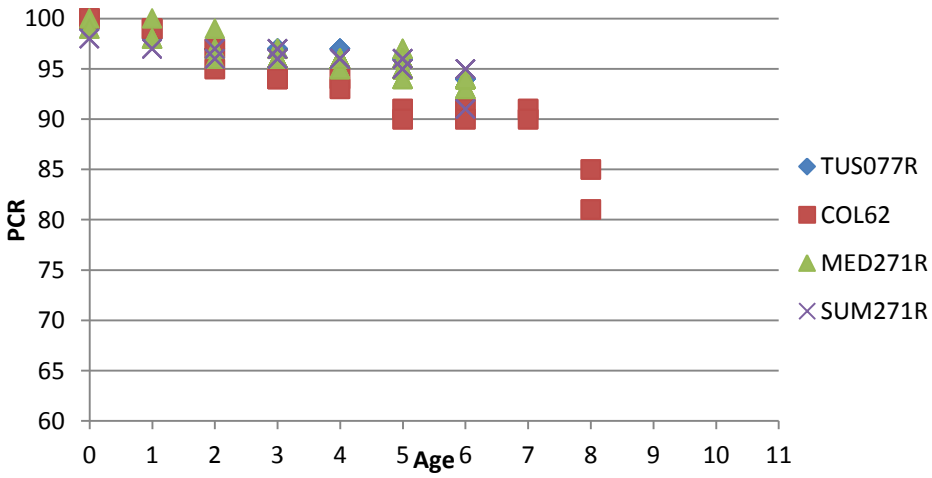

Figure 17 Pavement Performance of Individual Sections – MHB Type

7.2.2 Performance Model for Pavements Rubblized using RPB

The performance model for the RPB sections is presented in Figure 18. The fourth degree polynomial equation with an R^2 value of 0.53 indicates a reasonable fit. It can be inferred the performance of RPB sections resulted in a lot more variation as opposed to MHB. The individual sections used in the analysis are shown in Figure 19.

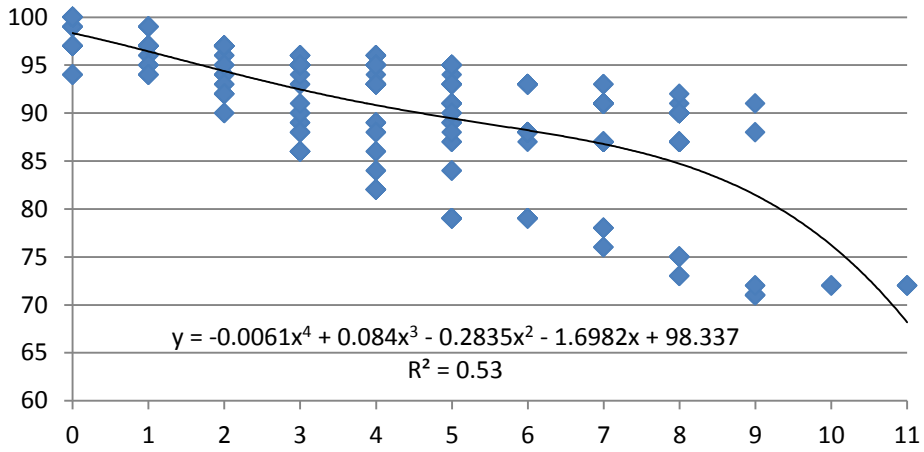

Figure 18 Pavement Performance Model – RPB Type

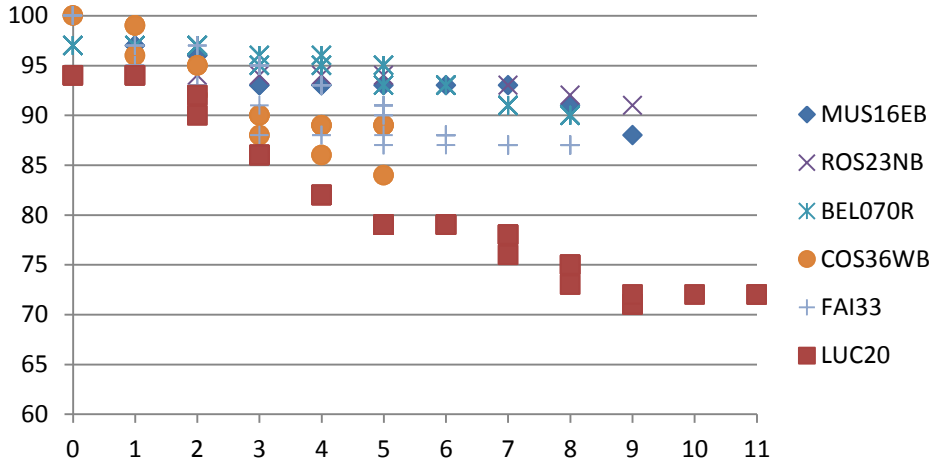

Figure 19 Pavement Performance of Individual Sections – RPB Type

7.3 Performance Model Based on Pavement Type

In order to investigate if the performance variation was due to the type of pavement namely, a) JRCP and b) CRCP, the dataset was categorized according to pavement type and the analysis was carried out.

7.3.1 Performance Model for JRCP Rubblized Pavements

A total of 571 PCR data points with respective age were available to develop the performance model. Figure 20 shows the performance curve along with a fourth degree polynomial equation and an R^2 value of 0.51.

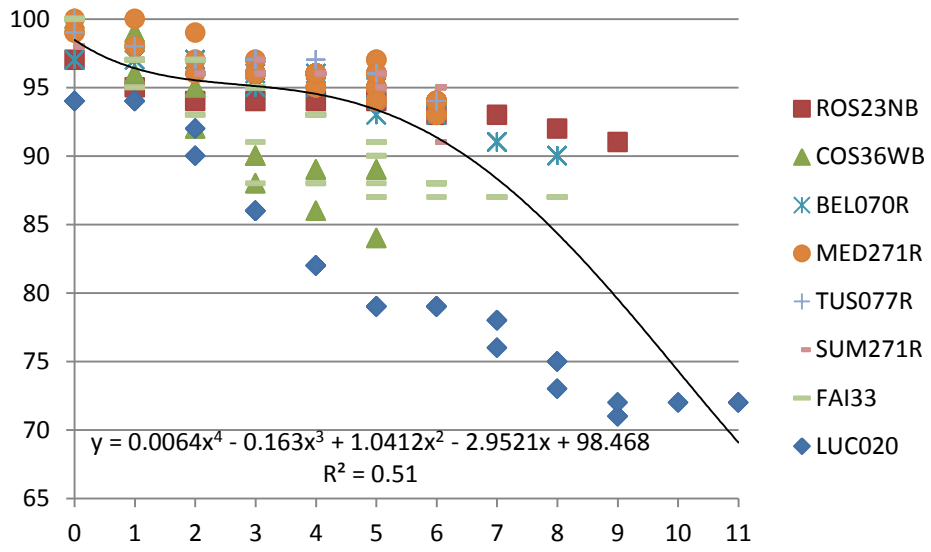

Figure 20 Pavement Performance – JRCP R/R Sections

7.3.2 Performance Model for CRCP Rubblized Pavements

Compared to the JRCP sections, there a fewer CRCP sections in Ohio. A total of 50 PCR data points from two R/R sections were available to develop the performance model. The performance curve, the model and corresponding R^2 value is shown in Figure 21.

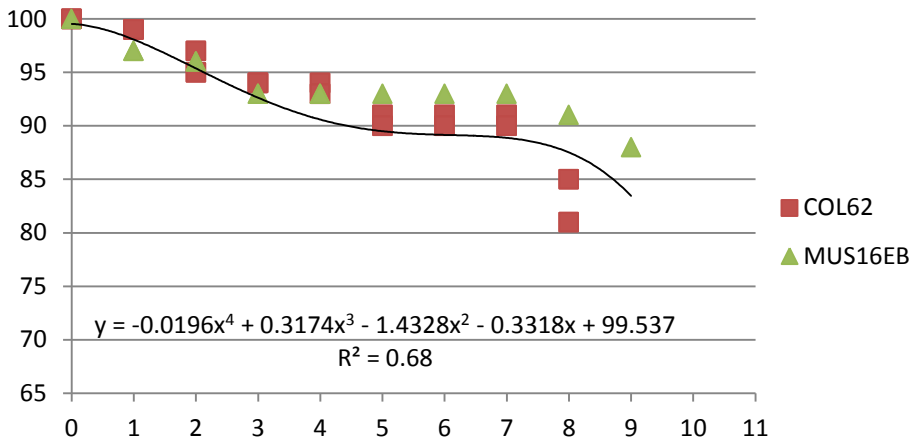

Figure 21 Pavement Performance – CRCP R/R Sections

8. DEFLECTION

The primary intent of deflection data analysis was to investigate and explore the structural condition of Ohio's R/R sections. While the PCR data was available for all the sections for each year, annual deflection was not available. As a part of this investigation, representative FWD deflection data was collected at the following R/R sections in 2008: CLA70, COS36, GRE35, FAI33, LUC20, and TUS77.

This one time deflection data was analyzed to derive the following four structural parameters:

1. Maximum deflection
2. Spreadability
3. Edward Ratio
4. Modulus of fractured PCC layer

Rubblization is expected to produce significant effect on the structural response and behavior of the resulting pavement. When compared to a rigid and/or composite pavement, the process should ideally lead to a reduction in the flexural strength, modulus of fractured PCC layer, and Spreadability and an increase in the surface deflection and Edward Ratio. In such an event, the behavior of the rubblized pavement will closely resemble that of a flexible pavement. Analysis of R/R deflection data was carried out to determine: (i) the extent to which the structural changes have taken place and (ii) the variation of structural parameters among the R/R sections.

8.1 Maximum Deflection

Thirty to forty FWD deflection measurements were made per lane-mile at each of the above mentioned R/R sections. The deflection data was processed to derive average Maximum Deflection measurements for each section. Simultaneously, a list of composite and flexible pavements from Strategic Highway Research Program (SHRP) Long Term Pavement Performance (LTPP) database with comparable base and surface layer thicknesses to that of Ohio's R/R pavement sections was selected. The LTPP sections selected are shown in Table 4.

Table 4. List of LTPP Sections for Composite and Flexible Pavement Sections

State Code	State	SHRP ID	Pavement Type
17	Illinois	7937	Composite
26	Michigan	7072	Composite
39	Ohio	7021	Composite
28	Mississippi	3097	Composite
48	Texas	7165	Composite
8	Colorado	7035	Composite
6	California	2004	Flexible
12	Florida	4108	Flexible
28	Mississippi	1013	Flexible
20	Kansas	1009	Flexible
34	New Jersey	1033	Flexible
6	California	2051	Flexible

The FWD deflection data from all these sections was processed to derive average Maximum Deflection values for each section. Figure 22 illustrates Maximum Deflection values for Ohio's R/R, SHRP Composite, and SHRP Flexible pavements. The average Maximum Deflection values for all three pavement categories are presented in Table 5.

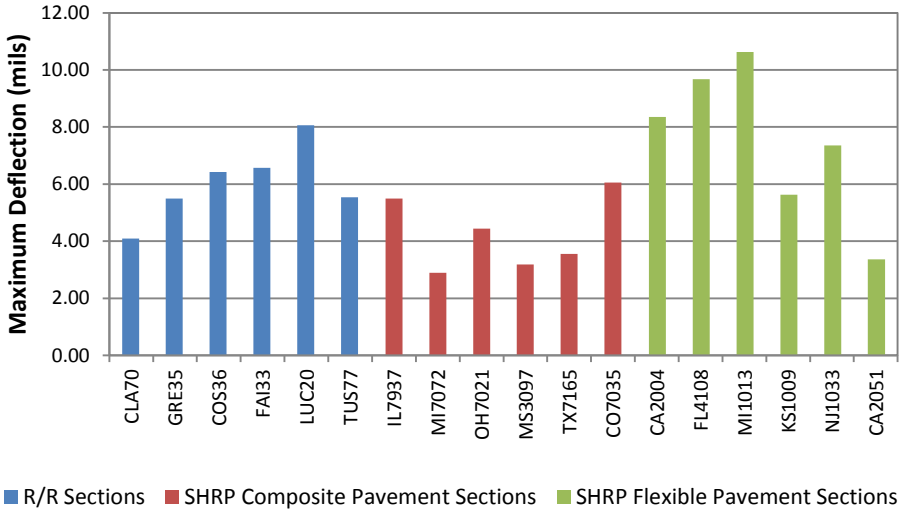

Figure 22 Maximum Deflection

Table 5. Rage of Maximum Deflection

Pavement Sections	**Range of Maximum Deflection (mils)**
R/R Pavement Sections	4.09 - 8.06
Composite Pavement Sections	2.89 - 6.06
Flexible Pavement Sections	3.63 - 10.63

A cursory look at Figure 22 suggests Maximum Deflection values of R/R pavements higher than that of Composite pavements and approach the values displayed by flexible pavements. A statistical test was performed to determine if the Maximum Deflection of R/R pavements resemble that of flexible pavements.

A two-tailed t-test at 95% confidence interval was carried out to compare the difference of means of Maximum Deflection between Ohio's R/R pavement sections and SHRP composite and flexible pavement sections. Results of the statistical hypothesis test are presented in Table 6.

Table 6. Results of Statistical Analysis of Maximum Deflection

Difference in Maximum Deflection Between	**Yes/No (*p*-value)**
R/R and Composite Pavement Sections	Yes (0.045)
R/R and Flexible Pavement Sections	No (0.267)

This analysis suggests the structural condition of R/R sections is comparable to that of flexible pavements.

8.2 Spreadability

Spreadability is a direct function of the load distribution characteristics of the materials used in the pavement layers. Computation of Spreadability requires entire deflection profile and provides a better representation of the structural condition of the pavements. It is calculated using the equation:

$$\text{Spreadability (\%)} = (W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7) \times 100 / 7W_1$$

Figures 23 shows the average Spreadability values for different sections.

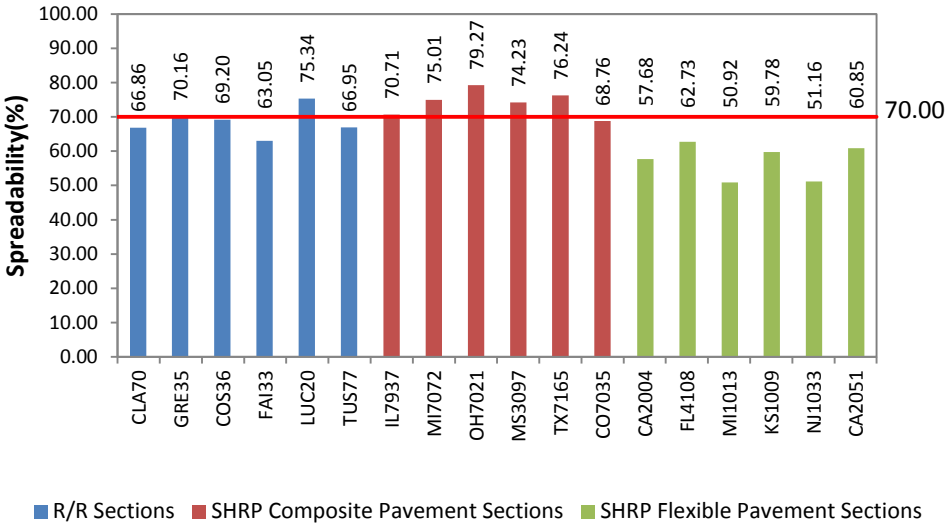

Figure 23 Spreadability

Materials with higher stiffness values distribute the load over a wider area. As such, the Spreadability of concrete and composite pavements is generally higher than flexible pavements. It can be seen from Figure 23 that majority of R/R sections exhibit Spreadability values under or very close to 70%, a value considered to be critical for flexible pavements. This again suggests rubblized pavements more like flexible pavements. In order to ascertain this behavior of R/R

pavements, a two-tailed t-test at 95% confidence interval was performed. Results of the t-test are presented in Table 7.

Table 7. Results of Statistical Analysis of Spreadability

Difference in Spreadability Between	**Yes/No (*p*-value)**
R/R and Composite Pavement Sections	Yes (0.041)
R/R and Flexible Pavement Sections	Yes (0.002)
Composite and Flexible Pavement Sections	Yes (0.000)

Although Figure 23 provides qualitative judgment indicating similarity in behavior of R/R and flexible pavements, the statistical t-test does not support this observation.

8.3 Edward Ratio

Edward ratio is defined as the ratio of W_1 and W_7 where W_1 is the maximum deflection and W_7 is the deflection measured at the seventh sensor using FWD. A ratio of W_1 and W_7 is considered as an indicator of the load spreading characteristics of pavement layer. If two pavements have nearly equal W_7 measurements, the values of the maximum deflections (W_1) would indicate the relative stiffness of the two pavements, with the weaker pavement exhibiting a higher maximum deflection. The ratio of W_1/W_7 for the weaker pavement would be higher than the other. This means, the higher the W_1/W_7 ratio, the lower the load spreading ability of the pavement. Using this rationale it can be stated that, rigid and composite pavements would exhibit

a lower W_1/W_7 value as compared to flexible pavements. It has been reported in a previous investigation [30] that pavements with Edward Ratios greater than 3.4 may be categorized as flexible pavements.

Figure 24 illustrates the distribution of Edward Ratio among R/R and SHRP pavement sections. It is clear from the figure that Edward Ratios of all R/R sections are greater than 3.4 and mirror the performance of flexible pavements. The results of the t-test are presented in Table 8.

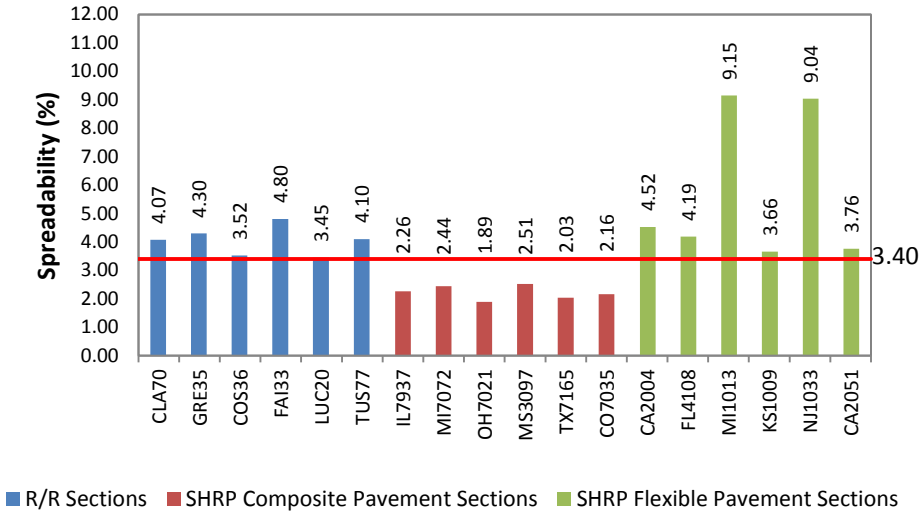

Figure 24 Edward Ratio (W_1/W_7)

Table 8. Results of Statistical Analysis of Edward Ratio

Difference in Edward Ratio Between	**Yes/No (*p*-value)**
R/R and Composite Pavement Sections	Yes (0.000)
R/R and Flexible Pavement Sections	No (0.185)

8.4 Modulus of Fractured Slab

Among the structural parameters investigated, the modulus of PCC layer perhaps best represents the structural condition of the pavement layers. This is because computation of modulus involves a comprehensive analysis of deflection data using layer analysis programs. Another reason why modulus can be considered as a significant indicator of structural condition of pavement is that modulus is a mechanistically derived parameter. The modulus values of pavement layers are necessary input in mechanistic-empirical pavement design/analysis procedures. Considerable research has been carried out to establish threshold values to categorize rigid and flexible layers. A study by NAPA [32] suggested a threshold value of 1000 ksi (6894.757 MPa) for the rubblized PCC layer beyond which reflection cracking is expected to occur.

The summary of modulus of fractured slabs for all the six R/R sections calculated using EVERCALC [33] is presented in Figure 25. The range of modulus values lie between 100 ksi and 309 ksi, with an average value of 272 ksi. It should be recognized here the primary intent of rubblization is to reduce the concrete pavement into smaller pieces so as to destroy the slab action, lower the stiffness values, and transform the pavement into flexible type. With the modulus values within 1000 ksi, regardless of the pavement breaker type, this analysis clearly illustrates Ohio's R/R sections have been effectively transformed into flexible layers.

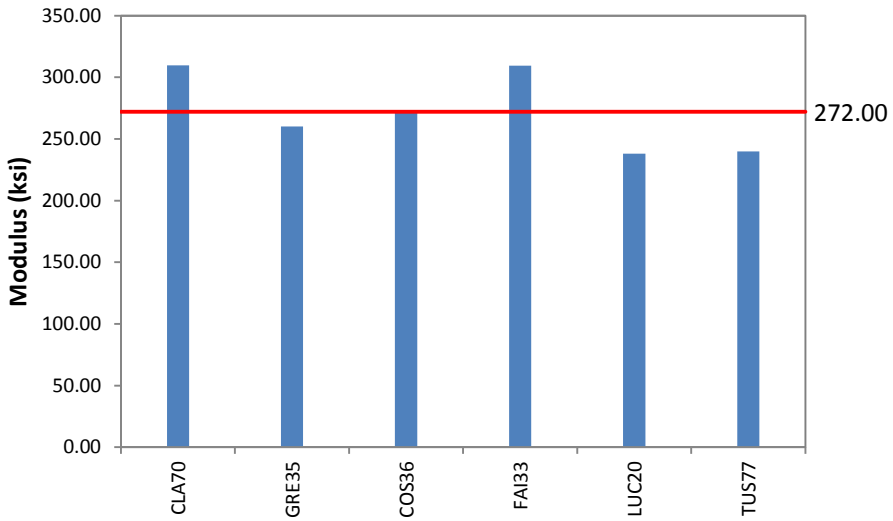

Figure 25 Modulus of Rubblized PCC Layers

9. DEMONSTRATION OF PAVEMENT BREAKERS ON RUBBLIZATION

The success of rubblization relies on the ability of a pavement breaker to break the intact concrete pavement into smaller pieces, in compliance with DOT specifications. Information about the resulting particle size of concrete fragments due to rubblization should be collected during the rubblization process. Field engineers will have to be vigilant and if rubblization is found to be out of specification, corrective measures should be implemented soon such as regulating the height and/or frequency of drop hammers. Normally, at the beginning of the job, the contractors set the energy required to rubblize based on the condition of the concrete slab, subgrade soil type and condition, and other field variables in order to comply with the specification. However, due to variations in these same variables (which are often hard to detect) through the project, the results of rubblization may not quite remain uniform. As a result, it has often been observed that the particles in the top layer, particularly above the steel

reinforcement, appear to be broken into smaller pieces in the range of 1 to 2" leaving larger than prescribed size fragments through the depth.

As stated in Section 3, ODOT's specification requires a majority of the particles in the range of 1 to 2" with no particles exceeding 6" in their largest dimension. ODOT's specification has been developed based on the assumption smaller fragments result in desired performance – a fact that should be substantiated with field data. In fact, data relating to performance of pavements with fragment size is not available in the literature either.

Analysis of functional and structural parameters of Ohio's R/R sections has, in general, indicated satisfactory performance of Ohio's R/R projects. However, there are variations between sections – some performing better than the others. Perhaps, one of the reasons for the variation in the performance may be due to the variation in the size of fragments through the depth of concrete layer. In order to investigate if the size of fragments did vary from project to project, accounting for the variation in the performance of pavements, it becomes necessary to gather data related to fragment sizes at each project in terms of average particle size distribution. Such data, which can only be collected during and just after the process of rubblization, is not recorded in ODOT's database or construction log books.

In 2006, the ODOT completed a study titled 'Investigation of Pavement Cracking on SR-4 and Demonstration of Multi-Head Breaker in Fracturing Reinforced Concrete Pavements Before Asphalt Overlay' [7]. One of the objectives of the study was to review the condition of selected break and seat (B/S) and rubblization projects constructed by ODOT. Two completed projects namely SR-4 and COS 36 were selected for this purpose. The pavement on SR-4 in Montgomery was rehabilitated in 1993 by breaking the existing concrete pavement and providing 6.5" thick AC overlay. The pavement on COS 36 was rehabilitated in 1998 by

rubblizing the PCC layer and constructing 9” thick AC overlay. Figures 26 and 27 show test pit on SR-4 while Figures 28 and 29 show test pits on COS 36. These figures depict a visual assessment of fracturing pattern and particle size distribution due to rubblization.

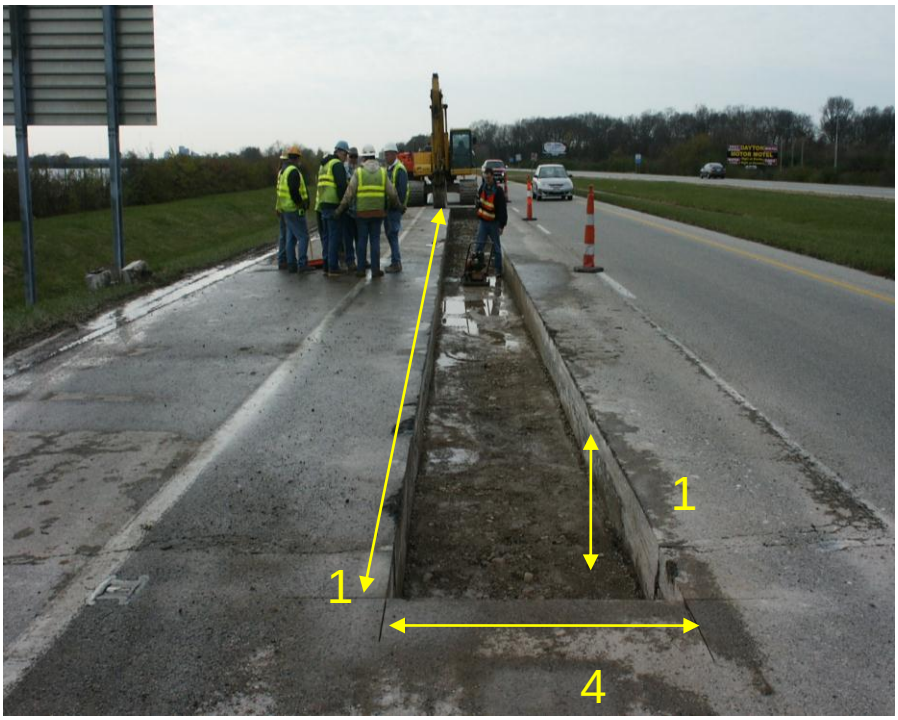

Figure 26 Test Pit on SR-4, Montgomery County, Mile 22.7-22.8 [7]

Figure 27 Exposed Slab Showing Fractured Particle Size and Shape [7]

Figure 28 Distribution of Particle Sizes on the COS-36 Project [7]

Figure 29 Maximum size of Particles on the COS-36 Project [7]

These test pits provided vital data about the pattern in which the concrete pavements were broken during rubblization, a data that was not available otherwise. Although, the size of the test pits were very small in comparison with the total project area, the information gathered was assumed to be a good representation of the work performed particularly in the absence of other sources of information.

Based on this experience, similar test pits were proposed on selected R/R sections. However, test pits could not be made on selected pavements since they were under warranty. At that time, a major rehabilitation project was underway on interstate 75 in Butler and Warren Counties (BUT/WAR-75) that included, among many items, removal and replacement of concrete pavement. As an alternate to test pits, the ODOT engineers proposed to utilize this opportunity to conduct a demonstration of the capability of the resonant breaker and the various MHBs to rubblize concrete pavement.

On the BUT/WAR 75 project, the prime contractor was using Specialties MHB along with a MHB developed by Wagway Tool Company. With the increasing number of breaking equipment and subtle differences in their designs and operating characteristics, it is imperative that there will be variability in the final product. Other agencies like Arkansas DOT and Alabama DOT have conducted studies to compare the rubblization equipment [20, 21]. However, these studies did not include all the equipment operating in the US. Hence in the ongoing research, it was proposed to include a comparative investigation of the four pavement breakers under similar roadway conditions.

Among the many benefits, the demonstration was expected help the state address issues such as: (i) revision of ODOT's current equipment specifications, and (ii) material requirements, in terms of size of rubblized fragments.

Figures 30, 31 and 32 show the location and layout of the demonstration site. A concrete pavement demonstration site was selected on BUT/WAR-75 between Station 95 and 135. The section was divided into four equal parts, each 1000' long. The four equipment manufacturers were randomly assigned one part each. A 1-day field demonstration was conducted in May 2009 to evaluate the capabilities of each pavement breaker.

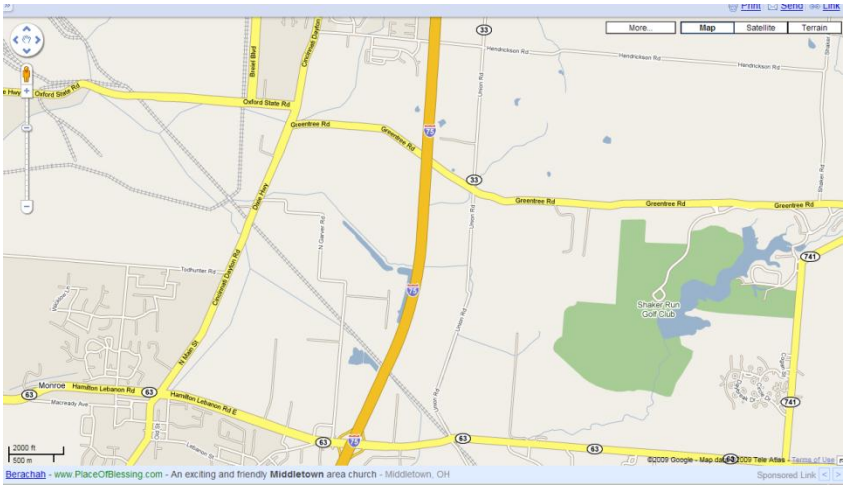

Figure 30 BUT/WAR 75-Rubblization Demonstration Project Location

Figure 31 General Layout of Rubblization Demonstration Site

Figure 32 Asphalt Layer Milled and Prepared for Rubblization

The following four pavement breakers participated in the study:

1. Resonant Pavement Breaker (RPB), owned by Resonant Machines, Kansas City, Missouri
2. MHB Badger Breaker, owned by Antigo Construction Inc., Antigo, Wisconsin
3. Specialties MHB, owned by Specialties Company LLC, Indianapolis, Indiana
4. Wagway MHB, owned by Wagway Tool Company, Indiana

Figure 33 through 36 show photos of these pavement breakers in operation.

Figure 33 Rubblization Using RPB

Figure 34 Rubblization Using MHB Badger Breaker

Figure 35 Rubblization Using Specialties MHB

Figure 36 Rubblization Using Wagway MHB

The existing asphalt overlay was removed by the general contractor (Jurgensen Company) to expose the concrete pavement. Each of the equipment manufacturers were provided with ODOT's rubblization specification item 320 and requested to rubblize 1000' long pavement stretch assigned to them. Figure 37 shows the segments allocated to each contractor.

Figure 37 General Layout of Demonstration Site

After rubblization, a vibratory steel roller was used to roll the surface. Figures 38 and 39 show a general view of rolled and finished surface. The entire process was documented by taking photos before, during and after rubblization.

Figure 38 Rolling With a Vibratory Steel roller

Figure 39 A View of Finished Surface

Evaluation of pavement breakers was made by investigating their ability to break the concrete pavement in accordance with ODOT's specification. A majority (> 90%) of particles in the top surface were broken into smaller pieces less than 2" in their largest dimension (Figure 40).

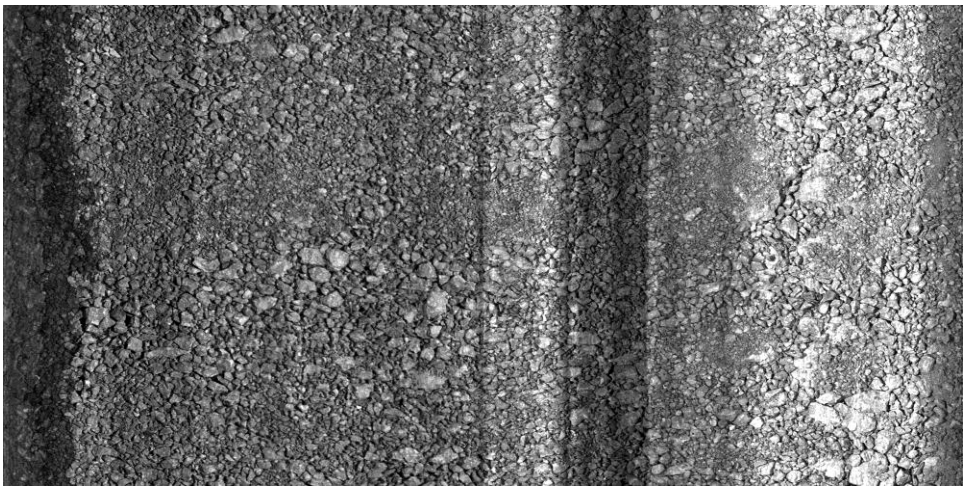

Figure 40 Top View of Rubblized and Rolled Surface

The fragmented particles in all the four segments were angular and consistent in size and shape. The finished surface was even, indicating no distortion of the base layer due to rubblization.

In addition to visual observation of particle sizes on the surface, a software namely WipFrag [32] was used for the analysis of particle size distribution. WipFrag is an automated image based granulometry system that uses digital image analysis of rock photographs and video tape images to determine grain size distributions. Using powerful edge detection algorithm, the system identifies edges of individual particles, constructs fragments outlines, and derives a particle size distribution curve. Figures 41 and 42 show the edge detection and fragmentation process while Figure 43 shows typical distribution of particles on the surface.

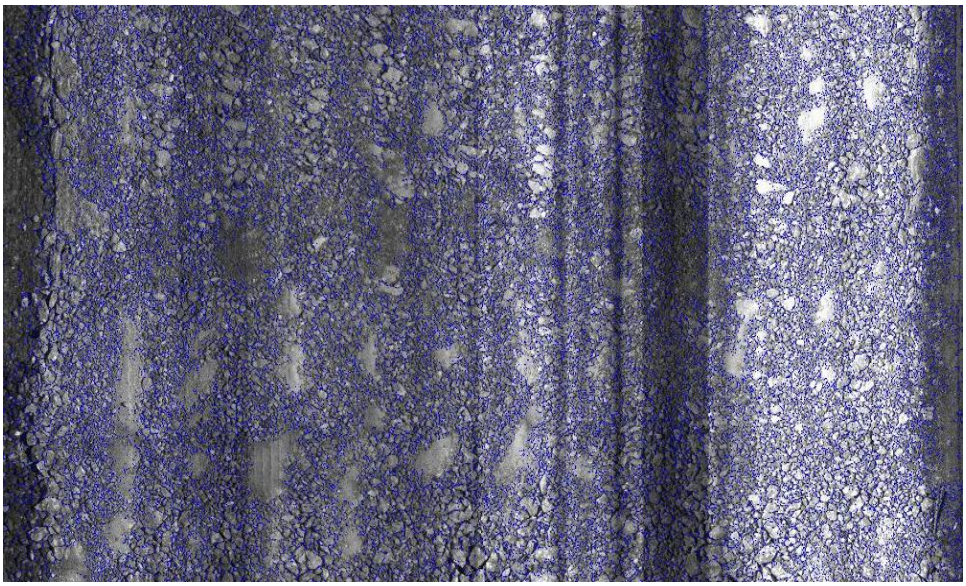

Figure 41 Edge Detection Process

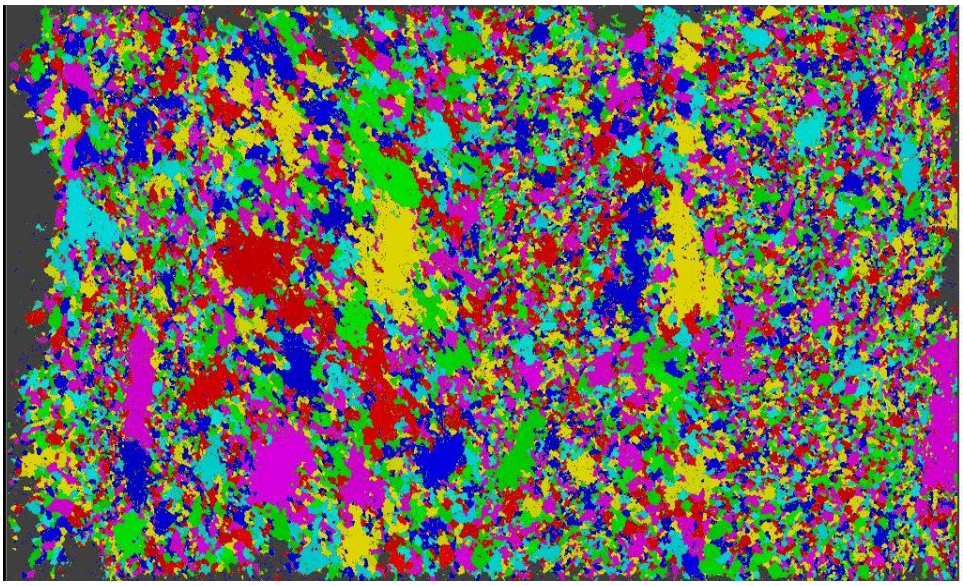

Figure 42 Fragmentation Using WipFrag

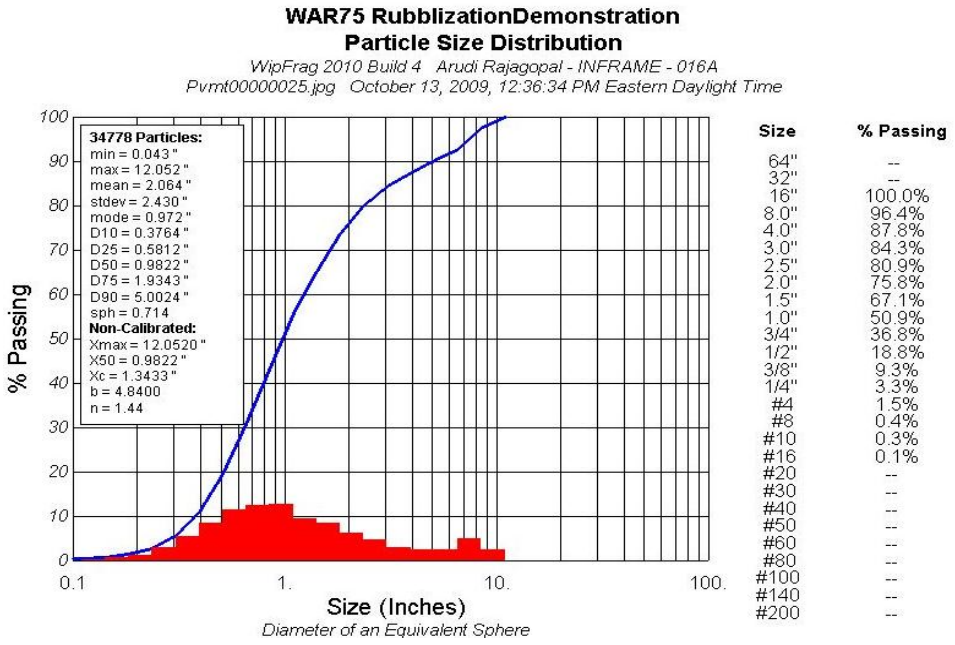

Figure 43 Grain Size Distribution of Surface Particles

Following this, two test pits were made in each of the four segments at randomly selection locations, one at a joint and the other at mid-slab location. Figures 44 through 48 show particles size distribution and steel reinforcement as well, observed in four test pits.

Figure 44 Test Pit Made in RPB Section

Figure 45 Test Pit Made in Antigo Section

Figure 46 Test Pit Made in Specialties Section

Figure 47 Test Pit Made in Wagway Section

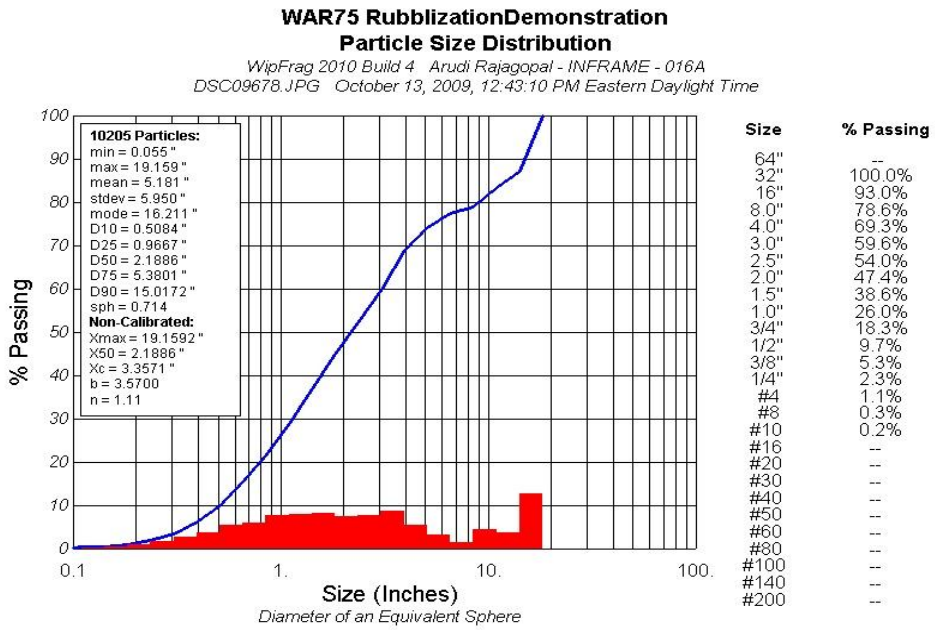

Figure 48 Grain Size Distribution of Particles in a Test Pit

Figure 48 shows analysis of particle size distribution in a test pit using WipFrag software. As it can be seen, the particle sizes through the depth were definitely much larger than those observed on the surface. Rubblization also resulted in angular particles and steel debonding. Three breakers namely, RPB, MHB Badger Breaker and Specialties MHB produced nearly satisfactory performance with more than 60% of the fragments estimated to be under 2" in their largest dimension, 20% between 2" and 6", 10% between 6" and 9" and the remaining 10% up to 12". However, Wagway MHB produced over 20% of the particles that were larger than 9" fragments.

In general, it was noted that ODOT's specification item 320.03 needs to be revised to accommodate other variants of MHB. More importantly, a fraction of the fragments produced by all the breakers exceeded ODOT's upper limit of 6". Although the effect of increasing the upper limit of fragment size from 6" to 12" on the performance of pavements is not predictable,

keeping in view the limitations of the equipment, it may be desired to change the size specification also.

10. CRITEIA FOR SELECTION OF CANDIDATE PROJECTS FOR R/R

When an in-service pavement is selected for R/R, the intent is to rubblize the concrete pavement into smaller fragments, in accordance with the DOT specifications. As noted earlier, several factors namely, type of breaker used, thickness and condition of concrete pavement, type and condition of underlying material – subgrade in particular may have contributed to the variation.

Manufacturers of pavement breakers have advanced their technology to vary the impact, frequency, and blow count of hammer for each job based on the site conditions, so as to accommodate site specific conditions and to derive the desired results. The fact that most states including Ohio have reported good to excellent performance of R/R pavements is a testimonial to this fact. However, two factors that need attention are the type and condition of subgrade soils.

Stiff soils offer better response to rubblization. Softer subgrade soils such clay, silt and soils that may be partially saturated provide reduced support to the overlying concrete pavement at the time of rubblizing, resulting in larger fragment sizes.

Developing appropriate criteria for the selection of candidate projects for R/R has been a topic of interest and challenge as well to the DOTs.

As outlined in the objectives, ODOT's existing specification for the selection of projects for rubblize and roll requires the SPT value of existing pavement to be greater than 15. This specification was established based on a review of projects but relying more on the field experience of geotechnical engineers. During plan preparation, ODOT's Office of Geotechnical

Engineering conducted SPT tests on BUT/WAR 75. A total of 11 borings were drilled in the area where the rubblization demonstration study was conducted. Eight borings exhibited blow counts below 15 blows per foot in the upper 6 feet of subgrade. The lowest blow count was 8 blows per foot, and the average was 11.

Based on the experience from this study, ODOT engineers generally agree that the criteria can be revised to include soils with SPT counts of 10 and above. As such, ODOT should consider revising the specification for the selection of candidate projects for R/R to include subgrade soils with SPT of 10 and above.

11. SUMMARY

During the last twenty years, many state departments of transportation have used 'Rubblization and Roll' as a major rehabilitation technique for the restoration of in-service concrete and composite pavements. The primary intent of the R/R method is to eliminate, delay, or lessen the severity of the reflection cracking problem. The DOTs have qualified and/or quantified the benefits of rubblization prior to the construction of asphalt concrete overlays. Some of the reported advantages of the R/R method include the following:

- Improved pavement performance
- Increased performance period
- Improved ride quality
- Reduced maintenance needs, and
- Lower life cycle costs

The present study initiated by ODOT is a part of its continuing effort to improve the quality and cost-effectiveness of pavements constructed in Ohio. The study was conducted in

three parts namely, (i) evaluation of Ohio's R/R projects, (ii) overview of national perspective, and (iii) field demonstration of pavement breakers. This report presents the details of the study and improvements where necessary.

11.1 Evaluation of Ohio's R/R Projects:

Since 1988, the Ohio Department of Transportation has used the R/R technique on 27 concrete pavement rehabilitation projects involving more than 2.0 million square yards. According to some estimates, an additional 200 miles of concrete pavements are slated for rubblization in the near future, costing the state well over $1.0 billion.

A preliminary review of Ohio's R/R sections by the department showed the R/R projects have, in general, performed well. However, there is some variation in their performance trends. Some sections had performed better than expected, while some may be quoted as '*underperformed*'. For the state to continue to use the R/R technique in the future, it is imperative that a thorough review of the R/R projects be made so as to understand the set of conditions under which the performance and benefits can be maximized. Needless to say, such an investigation would lead to establishment of best pavement rehabilitation practices. In view of this, the present study was conducted so as to:

- Systematically evaluate the performance of Ohio's R/R sections,
- Understand the factors that influence the performance of R/R pavements, and
- Generate data required for future application of R/R in Ohio.

Construction of Ohio's R/R sections has been done in compliance with ODOT's rubblization and roll specification item 320. As noted in the specification, there are two issues to be dealt with namely, (i) the choice of pavement breaker, and (ii) fragment size. ODOT allows

two types of breakers – resonant type (RPB) and multiple head breaker type (MHB). These breakers, although designed for the same purpose, have distinctly different operating characteristics. Fifteen sections used the resonant type breaker while the remaining 12 were rubblized with MHB. Previous experience in Ohio and elsewhere has shown the type of pavement breaker can cause considerable variation in the size and shape of broken fragments and hence, the performance of asphalt concrete overlays. As such, particular attention was paid in the present study to investigate the influence of pavement breaker and fragment size specification on the performance of R/R pavements.

Performance evaluation of each project was made using the following indicators:

- Pavement Condition Rating (PCR) data for each year during the performance period, and
- Falling Weight Deflectometer data, collected in 2008.

The PCR data was processed to objectively analyze the effectiveness of rubblization on the functional condition of the constructed pavements. To begin with, one comprehensive performance prediction model was developed by combining the data from all the R/R sections. This model indicated variation in the performance characteristics of R/R pavements and resulted in an R^2 value of 0.52. The average performance period of surface course of R/R pavements (the number of years required to reach a threshold PCR value equal to 65) was determined from this model to be 11.7 years.

To investigate the extent to which the type of pavement breaker may have induced variation in the performance, the PCR database was grouped according to the breaker type and two performance models were developed, one for each breaker type. This task yielded several interesting observations.

- The MHB sections showed less variation in performance and a significant improvement in R^2 value (0.79).
- Variation in RPB sections remained relatively high with R^2 equal to 0.53
- The MHB sections displayed higher PCR numbers during the first five years. However, a PCR degradation of about 15 points was observed during the subsequent 3 years. The performance period of surface course was estimated to be 9.4 years.
- The RPB sections, on the other hand, displayed variation between sections, starting from the initial period. PCR degradation was fairly consistent. The performance period of surface course was projected to be 11.3 years.

The FWD data from Ohio's R/R pavement sections was analyzed to derive structural parameters namely, Maximum Deflection, Spreadability, Edward Ratio and modulus of rubblized layer. In addition, similar data was collected on typical sections from SHRP composite and SHRP flexible pavement sections. The goal of this task was to compare the structural parameters of R/R pavements with available data from flexible and composite pavements. Comparison of Maximum Deflection and Edward Ratio values between R/R, Composite, and Flexible pavement sections indicated that structural behavior of R/R pavement sections closely resemble that of flexible pavement sections. This conclusion was validated by the statistical analysis. However, Spreadability values did not provide statistically valid evidence to make similar conclusion. The modulus of rubblized layers of all the R/R pavements was found to be less than 1000 ksi, an indication that the R/R layers have been transformed into flexible base.

11.2 National Perspective:

Data was collected from other states DOTs with intent to comprehend:

- How long the DOTs have been using the R/R technique,
- What is the performance trend of R/R projects in those states,
- What is DOT's experience and future interests in R/R practices,
- What type of specifications do the states adopt with respect to:
    - Size and shape of fragments,
    - Equipment (pavement breaker) specifications,
    - Quality control procedures in practice,
    - Criteria for selecting candidate projects for rubblization.

Fifteen states have routinely used rubblization as a concrete pavement rehabilitation technique. Based on a field review, most DOTs reported '*good to excellent*' performance. The experience and observation made by the other DOTs complement the findings of the present investigation.

Neither the data from the present study nor from other DOTs provided objective information regarding the optimum fragment size to maximize the effectiveness.

There is no unanimity among the DOTs regarding the choice of pavement breaker type, quality control issues, and rubblization specifications. A few states have undertaken extensive investigation to discern these issues.

Controlling the quality of rubblization process has always been a challenge to the field engineers and contractors as well. The only method currently available is by making test pits and subjectively assessing the particle size distribution. There is a need to address this issue and to develop a rational, non-destructive, procedure.

Selection of candidate projects for rubblization is another area that needs ratification. Current ODOT specification is based on standard penetration testing of subgrade soil. ODOT requires a minimum SPT value of 15 for the pavement to be eligible for rubblization. The only other state with a similar specification is Michigan DOT. In this report, a modification to the current specification has been recommended.

11.3 Field Demonstration:

A field demonstration of pavement rubblization was conducted in Ohio. The goals of the demonstration were to:

- Verify the compliance pavement breakers with ODOT's equipment specification,
- Demonstrate the capabilities of pavement breakers to rubblize under identical conditions, and
- Check the ability of pavement breakers to produce results stipulated in ODOT specification item 320.

Four pavement breakers, one RPB and 3 MHB type participated in the demonstration. While all the breakers were able to produce a large percentage of fragments ranging from sand size to 6" in size, none of the breakers could produce 100% of material less than 6", as required by ODOT. Approximately 10 to 20% of the fragments were 6 to 12" in size.

12. CONCLUSIONS

- R/R is an effective concrete pavement rehabilitation technique. Results show an overall improvement in pavement performance.
- The performance period of surface layer of R/R pavements is estimated to be 11.7 years.

- The application of preventive maintenance treatment, depending on the type used in Ohio, extends the performance period of the constructed pavement; thereby implying consecutive application of PM treatments will result in R/R pavements achieving or exceeding a design life of 20 years.
- Rubblization contributes to significant changes in structural condition; the process transforms the rigid concrete layer into a flexible base.
- Lately, there are several variants of MHBs. ODOT should consider changing the equipment specification to allow all variants of MHBs.
- There is no adequate data available to relate fragment size to performance. However, based on the data from the demonstration study, it is inferred ODOT should change the fragment specification to allow up to 12" fragments.
- ODOT's QC/QA procedure requires digging a test pit at the beginning of the project to investigate the size and shape of fragments. This procedure is not consistently applied in all projects. ODOT would benefit by adopting a more stringent QC/QA procedure. The use of WipFrag program can assist the field engineers and contractors to immediately and objectively determine the particle size distribution.
- It is important to review ODOT's policy regarding the criteria for the selection of candidate projects for rubblization and validate the threshold value established.

13. IMPLEMENTATION PLAN

The following changes to specifications re proposed:

- Item 320.03: Remove 'mounted laterally in pairs with half the hammers in a forward row and the remainder diagonally offset in a rear row'.

- Item 320.04: Adjust the rubblizing procedure to maintain the proper particle sizes. Control the speed of the rubblizing equipment such that: (i) 100% of the rubblized particles above the reinforcing steel is reduced to 1 to 2” in size, (ii) 90% of the rubblized particles below the reinforcing steel will not exceed 9” in their largest dimension, and (iii) no particles under the steel will exceed 12” in their largest dimension.
- Item 320.04: Rubblize the test section according to this specification. After rubblizing about 300’, the Engineer will designate a location within the 300’. Excavate a test pit to check for particle size through the thickness of the concrete. Additionally, check the particle sizes on the surface, approximately within 50’ on either side of the test pit. Using a standard digital camera with at least 1 MB resolution, take vertically downward images of particles in the test pit and at two locations outside the test pit within 50’. Use a fragmentation software such as WipFrag and generate a particle distribution curve. Following this, take digital images of the surface at every 1000’ intervals and analyze the particle sizes using the fragmentation software. Make test pits as and when necessary, such as change in subgrade soil, change in moisture condition. At least one test pit should be made for each production day or 7040 SY whichever is greater.
- GB 1: Rubblize and Roll rehabilitation technique is not an option when the minimum NL value for the subgrade soil is below 10.

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