GUIDELINES FOR AIRFIELD RUBBLIZATION

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ABSTRACT

Airfield Asphalt Pavement Technology Program (AAPTP) Project 04-01 called for the documentation of the state of the art in rubblization technology for airfield pavements and for developing guidelines covering project feasibility, thickness design/material characterization, quality assurance criteria and methods, and construction/equipment issues. The AAPTP 04-01 Final Report can be found at <u>www.aaptp.us</u>. This paper is an abbreviated description of the key findings from that report.

An extensive review of the literature on rubblization for both highways and airfields was conducted under this project. A comparison of current rubblization specifications was provided, along with a summary of all airfield rubblization projects known to date.

The combination of thin slabs (less than 9-inches) <u>and</u> weak underlying support (little to no subbase and soft subgrade that is often saturated) can produce marginal stability and difficulty in effectively rubblizing the PCC to specified criteria. A suggested criteria and protocol was developed for assessing the suitability of rubblization as a rehabilitation technique if the concrete slabs are less than 9 inches thick and have weak underlying support. Even when a significant portion of a project is assessed with a moderate to high level of risk, there are a number of recommendations and considerations in the planning, design and construction stages to optimize success.

Structural characterization of the rubblized layer is covered; along with other thickness design considerations such as minimum overlay thickness. To determine appropriate design modulus values for a rubblized layer, the literature was reviewed for studies where back-calculated modulus values of rubblized layers (E_{rub}) were determined. In addition, new back-calculations were performed for several projects, providing a total of 17 unique rubblized sections. The average in-place E_{rub} value was 205 ksi, with the absolute range being 100-430 ksi.

Quality control and assurance of the rubblization process is addressed, providing recommendations regarding test strips, test pits and particle-size acceptance criteria. Guidance on equipment and other issues are also covered.

INTRODUCTION AND BACKGROUND

Rubblization is the process of fracturing the existing Portland Cement Concrete Pavement (PCCP) in-place into small-interconnected pieces that serve as a base course for a new Hot Mix Asphalt (HMA) overlay. Rubblizing PCCP should result in the complete elimination of any slab action and subsequent reflective cracking into the new HMA. For concrete pavement with distributed steel, such as jointed reinforced concrete pavements (JRCP) and continuously reinforced concrete pavement (CRCP), the steel should be ruptured or the concrete-to-steel bond should generally be broken. Rubblization reduces the existing concrete pavement into a layer that resembles an aggregate base with a high degree of particle-to-particle interlock and is stiffer than most aggregate base layers. Since there are no hauling or disposal costs and all of the existing pavement materials remain in-place, rubblization is a very cost-effective rehabilitation method. The existing layers below the slabs, such as a aggregate or stabilized base, remain in

place to continue providing structural support. Some designers have placed a dense crushed aggregate base layer, or reclaimed HMA or PCC, over the rubblized PCC as a leveling course prior to the HMA. The HMA pavement is placed as a series of lifts, whose total thickness is determined in a manner similar to how a new flexible pavement would be designed. The net effect of rubblizing is to convert a deteriorating rigid pavement system into a new flexible pavement system.

Rubblization technology and equipment were initially developed to rehabilitate aging highway pavements; however, there is growing interest in using this technology for rehabilitating aging airfield pavements as well. For perspective, of the approximate 50 million square yards of PCCP that has been rubblized on hundreds of projects in the U.S. this past decade, about 98% has been on highways and only 2% on airfields. This 2% constitutes roughly 40 airfield projects scattered across the U.S. on a wide range of airfield types, from small general aviation to heavy loads. The widespread use and success of rubblization on highways provides the basis for tremendous payback potential when applying this technology to airfields. While rubblization has been deemed successful on the overwhelming majority of airfields projects, there are still many questions that remain when applying this technology to airfields. For example, highway PCCP thickness typically ranges between 8 to 12 inches, while airfields can be as thin as 6 inches or as thick as 25 inches. Another area where specific guidance for airfield rubblization is critical is in thickness design, since procedures for designing airfields varies greatly from traditional empirical highway procedures. While many state highway agencies have their own set of policies, procedures and specifications for using rubblization, these vary considerably from state to state. For this project, the challenge was to develop rubblization guidelines that are appropriate for the vast multitude of conditions that may exist on airfields across the country.

There are two basic types of rubblization equipment; the resonant pavement breaker (RPB) and the multi-head breaker (MHB). Both types can vary in size and weight depending on the model. The RPB is shown in Figure 1 and the MHB in Figure 2. The RPB is a self-propelled breaking unit that produces low amplitude (1/2-1 inch), high frequency (42-46) impacts per second (hertz) through a massive steel beam, often described as a "giant tuning fork." The vibrating foot rubblizes the concrete pavement in narrow strips as the machine moves forward along the unfractured edge of the pavement. The MHB is both a tractor and breaking unit, consisting of numerous pairs of 1,200 lb, 8-inch wide hammers mounted laterally across the breaking unit that produces continuous breakage from side to side. Each hammer pair operates independently and develops between 1,000 and 8,000 foot-pounds of energy (depending upon the drop height selected) and cycles at a rate of 30 to 35 impacts per minute. The MHB travels on unbroken slabs as it moves forward. Production rates for both the RPB and the MHB are generally from 6,000 to 8,000 yd² per unit per work shift, with thick airfield pavements being on the low end of this range.



Figure 1. Resonant Pavement Breaker (RPB)



Figure 2. Multiple Head Breaker (MHB)

STATE OF THE PRACTICE REVIEW

An extensive literature review was conducted as part of the AAPTP 04-01 project. Excellent industry manuals exist on rubblization including the Asphalt Institute's MS-17 and the National Asphalt Pavement Association's IS-132. The FAA Engineering Brief (EB) No. 66 and Specification P-215 on rubblization was reviewed thoroughly, with no major flaws found but with several areas not thoroughly addressed. TRB Circular No E-C087 was published in 2006 is and is an excellent consortium of six papers on rubblization. Performance studies by LA, CO, AL, IL, MI and other highway agencies all showed rubblization to be an effective and efficient rehabilitation alternative. In all the literature reviewed, there was no documented mention of reflective cracking ever occurring from underlying rubblized PCCP on any highway or airfield project. This is a significant finding since many design and research engineers get concerned when the particle sizes of the rubblized material do not completely meet criteria. Besides the literature, interviews conducted with many recognized rubblization experts helped shape the author's recommendations provided in the final 04-01 report.

There is also an extensive listing and discussion of the approximately 30 completed airfield rubblization projects in the 04-01 final report. The PCCP slab thicknesses of these projects have ranged from 6 to 26 inches. The Multi-Head Breaker (MHB) and Resonant Pavement Breaker (RPB) have fairly equally shared the rubblization market for airfields as well as highways, demonstrating that both types of rubblization equipment can be effective under a wide array on in-situ conditions.

A listing and comparison of current rubblization specifications from the FAA, USAF and state DOTs is also provided in the 04-01 final report. While the organization and format of agency specifications vary, most included similar headings for the different facets of rubblization. Comparisons within these different facets include General Description, Materials, Equipment, Construction Requirements and Method of Measurement/Basis of Payment.

ASSESSING PAVEMENT SUITABILITY

The combination of thin slabs (less than 9-inches) <u>and</u> weak underlying support (little to no subbase and soft subgrade that is often saturated) can produce marginal stability and difficulty in effectively rubblizing the PCC to specified criteria. World War II era airfields built in the U.S. and later converted into GA airfields often fit this category. Of the 30 airfield rubblization projects found with this study, 13 had slabs between 6-8 inches thick. On three of these, significant stability problems were reported while the other 10 apparently went well. The three projects with problems were Pratt Airport Runway in Kansas in 2005, USAF Kegelman Auxillary Field Runway in Oklahoma in 2006, and Tullahoma Regional Airport Runway Feasibility Trial in Tennessee in 2007. All three had PCC thicknesses less than 8 inches, no base and a very weak subgrade. Problems that can occur on these "marginally stable" pavements are large unbroken PCC pieces when either the MHB or RPB is used (Figure 3), rutting and "punch-thrus" by the RPB (Figure 4), and shifting/rotation of large PCC pieces by the HMA haul trucks or paving machines when either the MHB or RPB was used. All these lead to full-depth removal and patching of the damaged rubblized and underlying layers (Figures 5 and 6).



Figure 3, Ineffective Rubblization (Large PCC Pieces) at Pratt Due to Weak Support



Figure 4, RPB with High Flotation Tires Stuck in Unstable Area at Pratt



Figure 5, Excavation of Ineffective Rubblized Areas at Pratt for Full-depth Patch



Figure 6, Finished Patched Areas Outlined in White at Pratt using Crushed Aggregate

The author and his research team developed an evaluation protocol and risk assessment criteria for potential rubblization projects that contained these marginal support conditions (less than 9" thick PCC, little or no base, <u>and</u> weak and/or saturated subgrade). The evaluation protocol developed was modified from one newly developed by the Texas DOT and the risk assessment criteria were modified from the Illinois DOT.

The protocol collects information on the pavement structure through historical records, a visual condition survey, and in-situ testing that includes ground penetrating radar (GPR), falling weight deflectometer (FWD), and DCP. The GPR survey estimates pavement layer thicknesses, identifies changes in the pavement structure, and detects locations of wet subgrade or saturated voids. The FWD provides data to evaluate the structural condition of the pavement layers and overall pavement strength at one location relative to others. The DCP data serves for validation of base layer thicknesses and base and subgrade strength conditions. Once the evaluation data is collected and analyzed, rubblization can be assessed against the criteria in Figure 7. More details on the analysis are provided in the full report.



Figure 7, Rubblization Assessment Chart for Airfields

This evaluation protocol and chart should be used for evaluating airfield rubblization candidates where PCC slabs are less than 9 inches thick and support conditions are suspect. The high risk zone is indicative of areas likely to be problematic, the moderate risk zone of potentially problematic areas, and low risk zone of areas that should rubblize nicely. Airfield pavements with a substantial granular or stabilized base will fall in the low risk area and are good

rubblization candidates. On the other hand, thin slabs with no base and weak subgrade may fall into the moderate or high risk area. If the PCC plus base thickness is 6-8 inches, and CBRs are 10-14 (off the chart), we believe the appropriate risk level is moderate. The risk levels can be plotted versus station number to assess the relative risk over the entire project. The frequency of FWD and DCP testing, and overall robustness of the evaluation, will depend on a number of factors, including the level of concern based on current knowledge of in-situ conditions. This evaluation procedure allows the design engineer to predict the amount and location of full-depth repairs before the project starts, and once the rubblization process has started to adjust that prediction for the remainder for the project based on actual ability to rubblize under the known conditions. Unfortunately, there is little field data to validate the accuracy and recommended application of this chart. As with any new criteria, these guidelines need to be validated and possibly adjusted based on actual field experience. This can only occur with data collected from an evaluation similar to that prescribed here.

Even on projects where the pavement section appears to be uniform, some areas will rubblize while others may not due to subtle differences in subgrade and drainage conditions. It is helpful to have an estimate of unstable areas and also to know where the weakest support conditions may be expected. Pavements with a substantial subbase, or slabs \geq 9-inches, will not likely be problematic.

After reviewing all the national literature, project history and demonstration projects as part of this research, there is no compelling evidence to suggest that one type of equipment should be specified over the other for marginal support conditions. The RPB should certainly utilize the high-flotation tires when on marginal support. The MHB does not operate on broken PCC, while the RPB does, meaning the MHB won't rut an unstable rubblized pavement. This is not necessarily a big advantage for the MHB. Problems were encountered on a rubblization project in Texas when weak areas were not detected during rubblization with the MHB, but were later discovered during paving operations when trucks and pavers caused excessive distortion and shifting of the large broken PCC pieces. Finding weak areas during rubblization can be managed more easily versus finding them later during paving operations when plants are producing and trucks are delivering HMA to the jobsite. The RPB serves as a quasi-proof roller for finding weak areas during rubblization since two tires continuously operate on broken concrete.

RUBBLIZING ON MARGINAL PROJECT CANDIDATES

Even when a significant portion of a project has been assessed with a moderate to high level of risk, rubblization may still be the most attractive and economical rehabilitation alternative due to its many advantages. If so, there are a number of recommendations and considerations in the planning, design and construction stages to increase the probability of success.

Install Edge Drain System

Trapped water directly beneath the slabs will inhibit the rubblization process. Installing longitudinal edge drains is recommended for all rubblization projects, unless a well-functioning drain system exists or the subgrade is self-draining. The drains should be functioning at least two weeks before rubblization is assessed or the test strip is started.

Conduct a Feasibility Trial

When the risk level has been assessed to be moderate or high on a large portion of the project, a feasibility trial should be considered. In the trial at Tullahoma, both rubblization contractors were invited to demonstrate whether their equipment could effectively rubblize the project pavement before the final design was completed. If the pavement cannot be effectively rubblized, using a "modified rubblization" technique or designing as "crack and seat" may still be attractive alternatives. Both of these techniques are mentioned in the upcoming sections. Such a feasibility trial is very practical if the pavement is not operational, such as at Tullahoma. If the project pavement is operational, however, down time and repair considerations make such a trial difficult unless there is part of the pavement that could be closed for an extended period. If the risk assessment level is low for the majority of the project, a feasibility trial is not warranted.

Allow for "Modified Rubblization"

On marginally stable and thin PCCP, the MHB offers the advantage of being able to lower the hammer height and separate the impacts to allow the PCCP to be broken in a less aggressive manner that produces a more suitable surface for an HMA overlay. This "modified rubblization" technique with the MHB typically results in fractured concrete pieces larger than the sizing criteria normally allowed, but still can provide full-depth fracture and a surface suitable for an HMA overlay. A few states formally recognize this "modified rubblization" process where particle size criteria is waived by having a separate bid price (typically slightly less costly) and an estimated quantity in the bid documents. "Modified rubblization" should only be used when it has been deemed that the thin slabs and weak support conditions are preventing the specified size criteria from being met.

Consider Changing Design to Crack and Seat

While the "modified rubblization" technique appeared to be suitable during the feasibility trial at Tullahoma, the engineer and owner decided to redesign using conventional crack and seat. The crack and seat method utilizes a guillotine hammer to reduce the effective slab length by breaking it into smaller-sized pieces, ranging from 1 x 2 ft to 4 x 6 ft. Since the PCC pieces are larger than with rubblization, the resulting modulus is generally higher and a new thickness design may be appropriate. Crack and seat was a common rehabilitation method before rubblization became popular, and should remain as a viable fracture slab technology on plain jointed (no reinforcing steel) PCC pavements with thin slabs and poor support. Guidance on crack and seat is available from the Asphalt Institute's MS-17.

Include an Aggregate Leveling Course

Designing the new pavement section with a crushed aggregate base leveling course directly on the rubblized surface will minimize any difficulties with the rubblized surface being too rough or uneven. In addition to providing a smooth and dense surface for the HMA overlay, the aggregate layer should also act as a crack relief layer. This provides additional insurance that no reflective cracking will occur, especially if the rubblized pieces are larger than normally specified. Airfield projects have also utilized crushed concrete or reclaimed asphalt pavement (RAP) for a leveling course. While a leveling course will help protect the rubblized and underlying layers, heavy haul trucks, grading and compaction equipment must still deliver, place and compact the material. The haul trucks may pose critical loading on the exposed rubblized surface.

Include Separate Bid Item for Full Depth Patching

Providing an estimated quantity and separate bid item for full depth repairs will help ensure a competitive price for this work. In addition, costly delays and overruns will be minimized as the contractor will be anticipating these failed areas and have the necessary equipment and material for repair. From discussions with DOTs on candidates thought to be low risk, the full depth repair estimate should be between 5-10%, while for moderate risk a reasonable estimate is 15% full-depth repair.

Avoid "Wet Season" when Rubblizing

In line with installing effective drainage, the seasonal timing of the rubblization process can be critical to ensuring minimal moisture is under the PCC, as excessive moisture can inhibit rubblization. Scheduling the project to avoid a wet season, such as Spring, can make a big difference in how many problems are encountered with rubblizing thin PCCP.

Turn Roller Vibrators Off Under Wet Conditions

When rubblizing under wet subgrade conditions or when the water table is less than 5 feet from the surface, strong consideration should be given to turning the vibrators off during the roller operation immediately after the PCC has been fractured. Subgrade moisture will have a tendency to migrate up toward the bottom of the fractured slabs with heavy and repeated loadings, especially when these loads are vibrating.

Tracked HMA Pavers on First Lift

HMA pavers on tracks distribute the heavy HMA load better than pavers on wheels, making them desirable on thin PCC that has been rubblized. They also provide better traction on the loose rubblized surface, which is desirable when placing the first lift of HMA.

Sequence for HMA Trucks and MTVs to Avoid Rubblized

On an airfield, it may be possible to sequence the rubblization and first lift paving operation to where heavy HMA haul trucks and material transfer vehicles (MTVs) can operate on adjacent lanes that have not been rubblized in delivering the HMA to the paver. While MTVs are good to minimize segregation of the HMA and to allow continuous paving operations without stopping, they are also very heavy and should be used with extreme caution when on relatively thin PCC pavement that has been rubblized.

RUBBLIZED MATERIAL CHARACTERIZATION

To determine appropriate design modulus values for a rubblized layer, the literature was reviewed for studies where back-calculated modulus values of rubblized layers (E_{rub}) were determined. In addition, new back-calculations were performed for several projects, providing a total of 17 unique rubblized sections. The 17 data points are plotted in Figure 8 to show the relationship between modulus and slab thickness.



Figure 8. Average Initial Moduli versus Slab Thickness for All Sections Discussed

The average in-place E_{rub} value was 205 ksi, with the range being 100-430 ksi. This is significantly stiffer than that of a crushed aggregate base, which is assumed to have a modulus of 50-60 ksi. Rubblized modulus (E_{rub}) appears to be influenced by slab thickness (H), although there was a low R² correlation factor (0.32). Thicker slabs did tend to provide higher E_{rub} values.

The concept of "Retained Modulus" was explored. Retained Modulus is defined as the ratio of E_{rub} to pre-fractured PCC modulus (E_{pcc}) or E_{rub} / E_{pcc} . There were 13 sections (of the 17 sections) with sufficient data for determining E_{rub} / E_{pcc} . These are plotted in Figure 9.



Figure 9. "Retained Modulus" Percent versus Slab Thickness

Retained Modulus values were in the range of 1.8-13.5%, with an average of 6.0%. The thicker slabs tended to have higher E_{rub} / E_{pcc} values versus thinner slabs. The R² correlation factor between (E_{rub} / E_{pcc}) and (t) was fair (0.69). The concept of Retained Modulus needs to be explored further, but seems to make sense considering that the presence of reinforcing steel, hard aggregates, etc should have the same positive influence on both pre and post-rubblized modulus.

There was an indication on four separate projects that E_{rub} appeared to increase over time, albeit not at a consistent rate. While interesting, it is not recommended that this trend be considered when determining E_{rub} design values.

Rubblized modulus seems to be dependent on the level of rubblization. Repeat runs of either rubblization equipment were found to reduce E_{rub} as the concrete became more fractured. Thus, the fracture criteria specified, and its enforcement, can have an effect on E_{rub} .

Combining all the findings summarized above leads to no precise method for predicting E_{rub} during the design process. That being said, it does appear E_{rub} is somewhat related to slab thickness. The author recommends the following design ranges on airfield projects: For slabs 6 to 8 inches thick: E_{rub} from 100 to 135 ksi For slabs 8 to 14 inches thick: E_{rub} from 135 to 235 ksi For slabs >14 inches thick: E_{rub} from 235 to 400 ksi

OTHER THICKNESS DESIGN CONSIDERATIONS

When the CBR method of pavement design is used, characterizing the rubblized layer as a crushed stone base (CBR=100) is conservative. The author recommends using the following CBR equivalency factors (EF) to convert from rubblized to an "equivalent" crushed stone base: Rubblized Layer 6 to 8 inches thick: EF = 1.2Rubblized Layer 8 to 14 inches thick: EF = 1.4Rubblized Layer > 14 inches thick: EF = 1.6

Heavily reinforced slabs can cause concern regarding effectiveness of rubblization, as there can be significantly less fracture below the steel. That being said, there was no mention in the literature of any rubblized projects where reflective cracking occurred in the HMA due to poorly fractured PCC. Full depth fracture must be confirmed in the test pits.

There was no noted change in subgrade moduli values before and after rubblization.

There were no obvious trends or consistent differences between E_{rub} produced from the MHB and the RPB. Both types of equipment at different times and on various sections produced higher, lower, and similar E_{rub} relative to the other.

The <u>minimum</u> HMA overlay thickness is 5 inches if placing directly on rubblized. This must be placed in a minimum of two lifts, with the first lift at least 3 inches thick in order to achieve density. Unbound material such as P-209, RAP, etc is often placed first on rubblized as a leveling course for runways and taxiways to reestablish grade. If an unbound layer is placed

directly over rubblized, the minimum unbound layer thickness is 4 inches, and the minimum HMA overlay thickness criteria for that particular material should apply.

TEST STRIPS AND TEST PITS FOR QUALITY CONTROL

The purpose of a test strip and test pit is for the contractor to optimize his equipment operation and then demonstrate effective rubblizing and rolling practices for the in-situ conditions. Both are essential to a successful rubblization project and should be in every rubblization specification. Recommendations for the test strips are:

- Test strip location needs to be representative of the entire pavement feature to be rubblized.
- A new test strip (and test pit) should be performed when different conditions of slab age and thickness, reinforcing steel, support layers and thicknesses, and subgrade or moisture conditions are encountered.
- The dimensions of the test strip should be 300 ft long by one slab width.
- Any rolling (including proof rolling) performed on the project should be part of the test strip.

A test pit is excavated within each test strip to verify fracture was full depth and to the conditions specified, namely with regard to particle size and steel debonding. Recommendations for the test pit are:

- Desired test pit dimensions are the full slab width of the test strip by at least 6 ft long.
- Locate the test pit so that it includes a transverse joint and a longitudinal joint. Avoid locations that are near the wheel-path of normal aircraft traffic.
- Examine test pit rubble to determine if specification criteria have been met, including:
 - fracture through full depth of PCC slab
 - steel "substantially" debonded from concrete (dowels may be sawed at the joint if can't achieve "substantial" debonding)
 - o particle size requirements are met
 - o no contamination of subgrade fines into rubblized layer
 - o no shear distortion of the subgrade

If the test pit is located along a free edge, the sizes of the broken PCC pieces may be larger and "out of spec" at the outside edge (2-3 times slab thickness) due to the lack of lateral support during rubblization. This "out of spec" sizing should be allowed on these edges. Repair test pits by carefully discarding all excavated material and using high quality crushed aggregate or HMA as patch material and compacting in the necessary lifts.

The recommended particle size acceptance criteria for test pits is:

- Upper half of slab: No particles > 6 inches in any dimension, and at least 75% of material (by weight) < 3 inches in any dimension
- Bottom half of slab or below steel: Virtually no particles > than 2X the slab thickness, up to 24 inches, in any dimension.

On the rare occasion of an oversized piece, leave the piece in-place versus trying to remove.

Future concepts for improving current quality control/assurance practices include utilizing either deflection testing or intelligent compaction to:

- identify potential unrubblized areas
- find localized weak spots, and
- monitor the uniformity of the rubblized and other support layers.

OTHER RECOMMENDATIONS AND FINDINGS

In general, we recommend the installation of a longitudinal edge drain system for airfield rubblization projects and that it is operating at least two weeks prior to the start of rubblization. It is important that the edge drain be placed next to where the rubblized layer will be constructed and extends to the top of the rubblized layer.

The project plans should identify items that need to be protected from rubblization such as existing utilities, electrical fixtures, drainage inlets, adjacent pavements and other structures. The contractor is then responsible to operate his equipment in a manner that will not damage those items. Full depth isolation saw cuts are typically used as a means of protection.

The equipment descriptions provided in the FAA's P-215 and the Air Force's ETL 01-09 for the MHB is current. The description of the RPB in these two specs needs updating to allow for variation in frequency and greater amplitude. Any description should include "self-contained, self-propelled" to rule out the use of impact roller devices (i.e. *Impactor 2000*), wrecking balls, etc. These devices were developed for demolition and removal, and should never be used for rubblization. Both the MHB and the RPB have demonstrated they can be successful under a wide range of in-situ conditions.

A rubblization spec should allow the use of relief trenches as the contractor deems appropriate to allow for expansion of the concrete as it is rubblized.

All HMA must be removed prior to rubblizing the PCCP with either type equipment because the asphalt will absorb the fracture energy and inhibit good fracture of the PCC.

for smoothness or grade control, finish grading of the rubblized surface is not possible. Milling of the PCCP prior to rubblization for grade control has been done. Also, a leveling course of crushed aggregate of HMA has been used.

Applying a prime or tack coat on the rubblized surface is not recommended.

A windrow elevator to feed the hopper of the paving machine on the initial lift of HMA should not be allowed because of the risk of disturbing/dislodging particles at the surface.

It is best to keep traffic away from the rubblized pavement until all work is completed.

The cost of rubblizing has been between \$1.50 to \$2.50 per SY when both types of rubblization equipment is allowed. If only one type is allowed, the price range has been slightly higher at \$2.00 to \$3.00 per SY.

With regard to the concern that a PCCP suffering from Alkali-Silica Reaction (ASR) could potentially expand after rubblization to cause future differential swelling and subsequent roughness on the pavement surface, no mention of this concern was found in the literature or in speaking with rubblization experts. In addition, there has been a long history of highway and airfield projects utilizing fractured slab technology on ASR-infected PCCP and their long-term performance has been excellent.

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