Technical Information

Concrete Pavement Engineering and Research

INCLUDES:

Discussion on the theory for rubblizing a pavement's structure

Performance of rubblized concrete and asphalt overlay

Alternatives to Rubblization

- CPR
- Bonded Overlays
- Unbonded Overlays

Recommendations on when to rubblize a concrete pavement

Improved Design Procedures for Asphalt Overlays of Rubblized Concrete Pavement

Proposed Design Procedures for Concrete Overlays of Rubblized Concrete Pavement

Rubblizing of Concrete Pavements: A Discussion of its Use

Public agencies have been misusing rubblization and an asphalt overlay of concrete slabs as a rehabilitation technique for the last 10 to 15 years. It has been misused because most of the pavements that have been rubblized did not need rubblization. In most situations, either concrete pavement restoration (CPR) or a concrete overlay is a more appropriate and economical rehabilitation procedure. These procedures directly address why a concrete pavement is deteriorating and minimize further deterioration.

Rubblization is a destructive procedure that breaks an existing concrete slab into small fragments. This destroys the structural integrity of the pavement and reduces its load carrying capacity. Unlike CPR or concrete overlays, rubblization does not address the cause of the existing pavement deterioration and sometimes it can exacerbate the problem. For example, many concrete distresses are a result of poor support conditions. Rubblizing a pavement destroys the concrete slab's natural bridging action, causing the problems to become more pronounced. This can and has caused early failure of the asphalt overlay.[1]

The only appropriate time to rubblize an existing concrete pavement is when it has severe material durability problems, such as alkali-silica reactivity (ASR), D-cracking, or freeze-thaw damage. These material problems cause the concrete pavement to deteriorate and lose its structural integrity.

THE THEORY BEHIND RUBBLIZATION

Rubblization* breaks the existing concrete pavement into small fragments that range from sand size pieces to pieces approximately 100 mm (4 in.) to 200 mm (8 in.) in width. It was developed as an attempt to control the reflective cracking that occurs in an asphalt overlay of concrete. Reflective cracking is the cracking that occurs above a concrete pavement's joints. It happens because the asphalt overlay is too weak to withstand the daily and seasonal temperature movements of the underlying concrete.

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* Rubblization is just one type of fracturing procedure that destroys the concrete pavement. Crack and Seat (C/S) and Break and Seat (B/S) are two other types. C/S is used on JPCP and has a crack spacing from 300 to 1500 mm (12 to 60 in.). B/S is used on JRCP or CRCP and has a crack spacing from 150 to 600 mm (6 to 24 in.).

When an asphalt overlay is placed on an unrubblized concrete pavement, the concrete remains the main structural component of the pavement system. The asphalt layer acts mainly as a riding surface. When the concrete slabs expand and contract because of temperature changes, the joints open and close. However, the asphalt layer is too weak to withstand these movements. This sets up shear stresses in the asphalt-riding layer and it cracks.

To stop the reflective cracking, two fracturing procedures (Crack & Seat and Break & Seat) were developed to decrease the slab length. It was believed that if the slabs were shorter, the movements at the joints and cracks would be reduced and there would no reflective cracking. However, these initial fracturing processes were not successful. Even with the reduced movements of the smaller slabs, cracks eventually reflected through the asphalt overlay.

Rubblization is the reduction of the slab length to the extreme. It completely destroys the concrete's slab action by breaking it down into crushed-stone sized fragments. It is an attempt to turn the existing pavement into base course. However, there is one notable shortcoming to this analogy: a rubblized pavement has no gradation or density control. Specifications for base courses require both gradation and density control.[2]

In conclusion, rubblization (as well as Crack & Seat and Break & Seat) and an asphalt overlay does not address why an asphalt overlay cracks. Instead, these procedures destroy the concrete slabs so that the asphalt does not crack. However, this also destroys the main structural component of the pavement system and reduces its load carrying capacity.

PERFORMANCE AND COST

The performance of rubblization and asphalt overlay has varied from good to very poor. The key to good performance is properly assessing the conditions under the concrete slabs and the uniformity of the rubblized layer. However, this is very difficult, if not impossible, to do. As such, many asphalt overlays are severely under designed.

One example of this is Interstate 85 (I-85) near Greenville, South Carolina.[1] This overlay was built in 1998 and designed as a 200 mm (8 in.) asphalt overlay on a rubblized concrete pavement. During

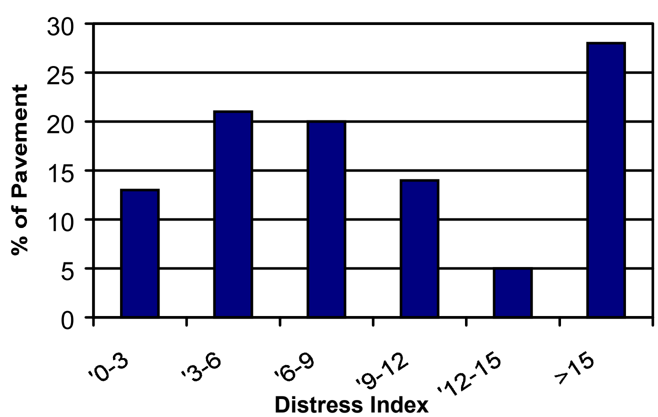
Rubblized concrete pavement.
Note the lack of uniformity in the rubblized material.[16]

construction, normal traffic caused severe rutting problems in the asphalt overlay. Upon investigation, it was found that the underlying soils were much weaker than determined before rubblization (before rubblization, the concrete was bridging over the weak soil).

To strengthen the pavement, the state needed to add 100-mm (4.0-in.) of asphalt to the 200-mm (8.0 in.) design. This supplemental asphalt added approximately $2.5 million dollars to a $15 million dollar contract.[1]

The state of Michigan has also had less than desired performance of their rubblized and asphalt overlaid pavements. The accompanying chart is from the Michigan Pavement Management System. It shows the 5-year distress index (DI) for 65.8 Km (40.9 miles) of rubblized and asphalt overlaid pavements. Note: a higher DI means poorer performance. [3]

The state requires that asphalt pavements with DI greater than eight be rehabilitated. Using this criteria, between 47-67% of the 5-year-old asphalt overlays on rubblized concrete pavements need rehabilitation. For concrete pavements, the state requires that they be restored when the DI is greater than four. If that criterion were used, then between 67-87% of the rubblized projects would need rehabilitation. Finally, it is important to note that approximately 28% of all the 5-year-old rubblized overlay projects have a DI greater than 15, indicating substantial distress.



Distress index distribution for rubblized concrete pavements and asphalt overlays in Michigan

In addition to poor performance, Michigan has seen that the costs of rubblization and asphalt overlays can be higher than concrete overlays. An example is a set of rehabilitation projects constructed on I-96.[4]

The first project, in Clinton County, is a 190-mm (7.5 in.) concrete overlay built in 1991. The second project, in Ingham County, is a 152-mm (6 in.) asphalt overlay on rubblized concrete done in 1992. The cost of the concrete overlay was $1,034,000 per mile. The cost for the rubblization and asphalt overlay was $1,437,500 per mile. This is 39% difference in the initial costs of the projects.

Even with the most controlled experiments, rubblized concrete and asphalt overlays have had poor performance. The photos on the next page are from a rubblization project in the Strategic Highway Research Program (SHRP) constructed in 1992.

The project is in the southbound lanes of I-35 in Kay County, OK. The first photo shows a 100-mm (4-in.) asphalt overlay on a rubblized 228-mm (9-in.) jointed reinforced concrete pavement. The second photo shows an 8-inch asphalt overlay on the same pavement.

100-mm asphalt overlay on rubblized JRCP

200-mm asphalt overlay on rubblized JRCP

A 1994 report[5] stated that both these projects were controlling the reflective cracking. However, since that time, both have developed a considerable amount of longitudinal and fatigue cracking in the wheelpaths. Though the 200-mm (8-in.) overlay is outperforming the 100-mm (4-in.) overlay, it still has a considerable amount of distress considering it has only been in service for 6 years.

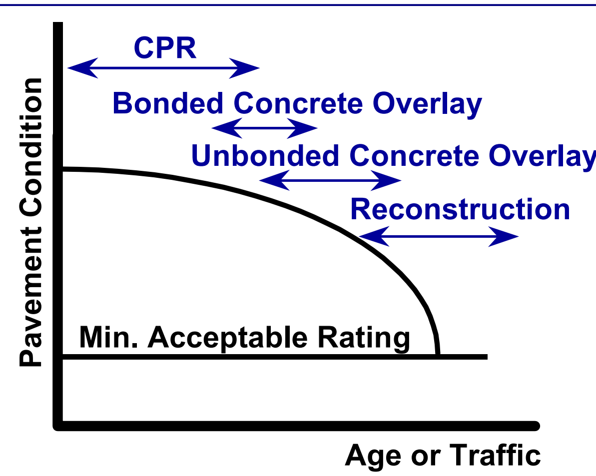
Overall, the performance and cost data shows that an asphalt overlay of a rubblized concrete pavement is a short-term solution that lasts between 8 and 12 years. Because of its short life, a rubblized concrete pavement with an asphalt overlay requires more repairs and is more costly when compared to other concrete pavement rehabilitation options.

Alternatives to Rubblizing and Asphalt Overlay

Concrete pavement restoration (CPR) and concrete overlays are procedures that keep and use the intact structural integrity of an existing concrete slab. Unlike rubblization, CPR and concrete overlays directly address the cause of the problems in the pavement. Therefore, they are much more appropriate and viable solutions.

Concrete Pavement Restoration

CPR is a series of engineered techniques that repairs isolated areas of deterioration in a concrete pavement. Appropriate and timely CPR maintains the pavement in a smooth, safe, and quiet condition and extends its service life on average by 9-10 years. This is about the same life expected of an asphalt overlay of a rubblized concrete pavement. Some CPR projects have performed for more than 17 years.[6]



Life Cycle diagram showing appropriate pavement rehabilitation strategies and where they relate to pavement condition

Table 1: Concrete Pavement Restoration Techniques	
Concrete Pavement Restoration Technique	***Used to:***
Full-Depth Repairs	Repair cracked slabs and joint deterioration
Partial-Depth Repairs	Repair joint and crack deterioration and surface distress
Diamond Grinding	Extend serviceability; improve ride and skid resistance; reduce noise
Dowel-Bar Retrofit	Restore load transfer at joints and cracks
Joint and Crack Resealing	Minimize infiltration of water and incompressible material into joint system
Slab Stabilization	Fill small voids underneath the concrete slab
Cross-Stitching	Repair low and medium severity longitudinal cracks
Grooving	Reduce wet weather accidents and prevent hydroplaning
Retrofitting Edge Drains	Add a longitudinal drainage system
Retrofitting Concrete Shoulder	Decrease pavement edge stresses and corner deflections

Table 1 shows the CPR techniques. Each technique is specifically designed to repair or prevent the recurrence of a certain distress or a combination of distresses. While each technique can be used individually, they are more effective when several are used together. In some cases more than one CPR technique may be applicable. However, one technique is usually more suitable than the other because of the condition of the pavement.

CPR has several advantages over rubblizing. First, it repairs the isolated areas of distress that need repaired without destroying the structural integrity of the slab. This fundamental difference makes CPR more effective and less costly than rubblization and asphalt overlays.

In addition, CPR does not limit future pavement rehabilitations options. Once a pavement has been rubblized, it can only be overlaid. After CPR, all overlay, CPR, and recycling options are still available when the pavement needs its next rehabilitation.

Diamond Grinding of an old concrete pavement to restore smoothness

Finally, CPR does not have to be placed over the entire pavement width, as does an asphalt overlay. This maintains the existing grade of the pavement and means features such as curbs and gutters, bridge clearances, and roadside appurtenances do not need adjustment. These advantages makes CPR quicker and cause less traffic disruption than rubblization and an asphalt overlay. For more information on CPR, see references 6-11.

Concrete Overlay Alternatives -

Concrete overlays provide two important functions. First, they improve the surface characteristic of the pavement (rideability, safety, skid resistance, cross-section and surface defects, etc.). Secondly, they increase the structural capacity of a pavement. There are two basic types concrete overlays for existing concrete pavements: bonded concrete overlay and unbonded concrete overlay. Each overlay technique has its own unique characteristics.

Bonded Overlays

Bonded concrete overlays consists of a thin concrete layer (usually 100 mm or less) bonded to the top of an existing concrete surface. They are used on pavements that are in good condition with little deterioration in order to increase their structural capacity. The bond causes the overlay and existing pavement to act as one thick slab. A good candidate for a bonded overlay is a pavement that has little deterioration, but is too thin due to increased truck volumes (i.e., it is only 150 mm (6.0 in.) when it should actually be 230 mm (9.0 in)).

In order to ensure that bond develops, specific steps are taken to prepare the surface of the existing pavement. This is done with either shotblasting and milling. With shotblasting, steel shot are hurled at the pavement surface to remove about 3 mm (0.125 in.) from the pavement surface. This creates a rough and extremely porous surface that increases the mechanical interlock and provides a strong bond. Milling is primarily used where deeper removal is desired. It typically removes between 6 and 25 mm (0.25 and 1.0 in). Afterwards, a secondary cleaning is required, which is typically shotblasting.

Surface preparation and cleanliness is the key to long-term bond development and overlay performance. If the surface is properly cleaned, and the existing pavement is not too deteriorated, bonded concrete overlays can last for over 15 years without any, or very little maintenance work. However, when they are placed on a pavement in poor condition, they do not perform well.[12] For more information on Bonded Concrete overlays, see reference 13.

Shotblasting the surface in preparation for a bonded concrete overlay.

Ultra-thin Unbonded Overlays – An Untested Alternate.

One of the problems with traditional unbonded overlays is that they are usually fairly thick (150 to 250 mm (6 to 10 in.), depending on traffic and sight conditions). A recent development, used on existing asphalt pavements, is Ultra-Thin Whitetopping (UTW).

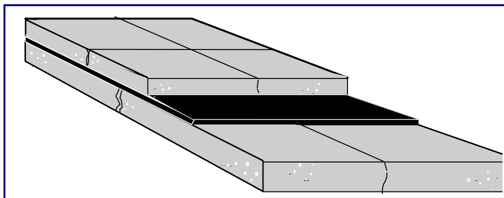
One of the reasons that UTW's work is because of their short joint spacing. The short joint spacing allows the pavement to act like a cast-in-place block system. It has been reasoned that a thin unbonded overlay, with short joint spacing, may behave in much the same way and provide 8 to 15 years of service.

The Pennsylvania DOT built a 3.5 inch ultra-thin unbonded overlay on a ramp in Hershey, PA in 1995. Though it has not had long-term monitoring, early investigations show that it is performing well and should be considered as an alternative for milling and overlaying with Hot Mix Asphalt.

Unbonded Overlays

An unbonded concrete overlay consists of thicker concrete layer (125 mm or greater) on top of an existing concrete pavement. It uses a thin asphalt separation (stress relief) layer, placed between the new and existing concrete, to separate the two layers so that they act independently of each other. Because the two concrete layers are independent, unbonded overlays react structurally as if built on a strong, non-erodable base course. For this reason, unbonded concrete overlays are a much better option for deteriorated concrete pavements than rubblization and an asphalt overlay.

One of the concerns with unbonded concrete overlays is that the distresses from the lower concrete layer will reflect into the new overlay. Fortunately, the separation interlayer acts as a cushioning layer that prevents distresses from the underlying concrete from reflecting into the overlay. Additionally, because the pavement is on a strong, non-erodable foundation, load induced distresses such as loss of support, pumping, faulting and corner breaks are minimized. Overall, the structural capacity of the overlay is enhanced because of the existing intact pavement.



Schematic of an unbonded overlay. Note how the Asphalt layer separates the two concrete layers so that they act independently.

Another advantage of unbonded overlays over rubblization and asphalt overlays is that they do not require that the existing slab be broken. Therefore, traffic can be maintained on adjacent lanes and shoulders during construction. This is a critical issue in constricted and congested areas.

The performance of an unbonded overlay has been very good. Studies done by the National Cooperative Highway Research Program (NCHRP) have shown that unbonded overlays have performed well for over 20 years.[12] Where there has been poor performance, it has usually been caused by an inadequate separation interlayer. The separation interlayer must isolate the overlay from distress and horizontal movement in the existing pavement. For more information on Unbonded Concrete overlays, see reference 14.

When to Rubblize an Existing Concrete Pavement

Rubblization should never be used on a pavement that is structurally sound. Destroying a structurally sound pavement in order to minimize reflective cracking is poor practice and a waste of resources. It is much better to save and use the structure of the existing pavement.

Furthermore, rubblizing a structurally sound pavement eliminates all other current and future pavement rehabilitation options. Once a pavement is rubblized, the only thing that an agency can do with it is overlay it. Later, this could cause problems with elevated crowns and raised grades for future rehabilitations. Keeping the pavement intact keeps all options open for future rehabilitations.

Rubblization is an appropriate solution when the existing concrete slab exhibits material problems such as alkali-silica reactivity (ASR), D-cracking, or freeze-thaw damage. These material problems cause the concrete pavement to deteriorate and lose its structural integrity.

ASR reduces the durability of concrete by creating a gel that may absorb water, expand, and crack the concrete. Once cracked, the concrete loses it strength and deteriorates. D-cracking occurs when certain aggregates in a concrete mixture become saturated, freeze, and expand. This expansion causes the surrounding concrete to crack.

Freeze-thaw damage occurs in concrete that has a poor entrained-air system. Entrained air is a system of microscopic air bubbles in the concrete that protects it as it freezes. If the volume and spacing of the air bubbles is not adequate, the concrete cracks when it freezes. All three of these material problems typically takes several years to occur and the degree of deterioration depends upon the amount of poor materials in the concrete.

The Rubblization Procedure

There are two pieces of machinery used to rubblize concrete pavement: the resonant breaker and the multihead breaker (MHB). Though both machines break the slab into smaller pieces, neither one breaks the concrete into the uniform high quality base course that they claim. Instead, rubblization produces a broken concrete that ranges from sand size particles to fragments that are approximately 150 to 200 mm (6 to 8 in.) in width, with no gradation or density control.

The resonant breaker has a 150-mm (6-in.) wide head that vibrates at a low amplitude and high frequency. As it vibrates, it impacts and shatters the slab. However, this small head can only break a small, longitudinal strip at a time. Thus, it requires about 50 passes to completely break a 7.3 m (24 foot) wide pavement.

The multihead breaker (MHB) pulverizes an entire lane in a single pass. However, it uses high amplitude drop hammers that impact the concrete and crushes or breaks it in flexure. As such, it is not rubblization, it is pulverization.

Besides not providing a uniform base, both pieces of equipment can damage and introduce variability into the subgrade support. With the resonant breaker, the subgrade can be damaged because two of its wheels, which are around 20,000 lbs. each, must ride on the broken concrete, which can push the broken concrete into the underlying subbase or subgrade.[15] The MHB damages the subgrade when its forceful crushing procedure impacts the concrete and pushes it into the subbase or subgrade.[16]

Once the subgrade and subbase is damaged, it no longer provides uniform support. This must be taken into account in the design procedure or it must be removed and repaired during the construction procedure.

The importance of subgrade support.

Eventually, the subgrade carries the load of any pavement. Therefore, it is very important that it be characterized correctly.

The main deficiency with rubblization is that it is difficult to predict the subgrade conditions until after rubblization.

Testing on top of the intact concrete does not guarantee correct characterization of the subgrade. In many cases, the concrete's natural bridging action will cover up a weak subgrade and masks its true strength.

A good rule for judging how a rubblized pavement will perform is to look at the performance of the existing concrete. If the existing concrete is deteriorating due to poor support, then rubblization will also have problems due to poor support.

Designing an Overlay on a Rubblized Concrete Pavement

Once it has been determined that a pavement has a materials problem and is good candidate for rubblization, the pavement engineers must properly select the overlay thickness. Though most overlays have been asphalt, it is possible to place a concrete overlay on the rubblized concrete pavement. In either case, the most important aspect of the design procedure is the characterization of the rubblized concrete layer.

Asphalt Overlay

Structural coefficients describe the strength of the layer. The higher the value, the stronger the layer.

AASHTO recommends the following structural coefficient values for the design of an asphalt overlay on rubblized slabs:

New Asphalt Concrete
0.20 – 0.44

Rubblized Slab
0.14 - 0.30

Base Course
0.0 - 0.14

These values are reasonable, except for the rubblized slab. An stabilized material has a structural coefficient value of 0.20. The upper values for rubblized slabs are higher than for the stabilized materials. This indicates that the broken slabs are stronger than an intact stabilized material.

The most recognized design procedure for asphalt overlays of rubblized concrete is the AASHTO Overlay Design of Fractured slabs.[17] This procedure uses the concept of structural numbers (SN) and layer coefficients (a) to determine the thickness of the overlay. The basic equation to determine the asphalt overlay thickness is:

$$t_{asph} = \frac{SN_{req} - (a_{rub\ conc} * t_{rub\ conc} + a_{base} * t_{base})}{a_{asphalt}}$$

Where

SN_{req} = required structural number to carry the future traffic

a_i = structural coefficient of the asphalt, rubblized concrete, or base course

t_i = thickness of the asphalt, rubblized concrete, or base course

The key to the AASHTO design procedure is correctly quantifying the contribution of the rubblized layer. However, because rubblization is not done until construction, this is a difficult procedure.

Complicating the problem is the fact that the rubblized material is not uniform and difficult to characterize. The AASHTO Guide for Design of Pavement Structures states that there is "a wide range of backcalculated modulus values among different projects, from 100,000 psi (690 MPa) to several hundred thousand psi, and within project coefficient of variation of as much as 40 percent." [17]

In a recent research project, *Structural Coefficients for Fractured Concrete Slabs,*[18] an attempt to develop realistic values was undertaken. In this research, the structural coefficients were developed by relating the overlay thicknesses from both the rigid and flexible asphalt overlay models used in the AASHTO Guide.

The AASHTO Guide uses two models to design asphalt overlays of concrete. One is used for asphalt overlays of intact concrete and is based on rigid pavement modeling. The second is based on flexible pavement modeling and is used for asphalt overlays of asphalt pavements and fractured slabs.

For a given traffic volume, these two models should give the same structural capacity. Using this premise, the research related the overlay thicknesses from both the rigid and flexible asphalt overlay models and developed the structural coefficients so that the structural capacity from the two methods were as close as possible to each other.

Rubblized slab thicknesses from 180 to 280 mm (7 to 11 in.) were investigated. It found that no single value for the structural coefficient of a rubblized slab yielded equivalent overlay designs for the full range of the existing slab thicknesses. The structural coefficient value varied based on the expected traffic values.

Overall, the structural coefficient range was between 0.149 to 0.245, with an average value of 0.197. The values at the low end of this range are appropriate for larger future thickness requirements (high traffic volumes), while values at the high end are more appropriate for smaller future thickness requirements (low traffic volumes).

Based on the results of this analysis, ACPA recommends that a range of 0.14 to 0.25, with a midrange of 0.20 be used in the current AASHTO design procedure for asphalt overlays of rubblized pavements. For high volumes of traffic, the lower structural coefficient values should be used and for low volumes of traffic, the higher values should be used.

Rubblizing and Concrete Overlay

Though not used as often, it is possible to place a concrete overlay on a rubblized concrete pavement. This technique has been extremely successful in both Pennsylvania and Iowa. Furthermore, because concrete overlays last 25 years or more while asphalt overlays typically last only 10 to 15 years, the concrete option is a better long-term solution.

Still, particular care should be used in the decision to rubblize the existing concrete pavement because it will reduce the structural capacity and likely warrant a thicker concrete overlay. The benefits of improved load transfer from sleeper-slab action, and decreased potential for pumping are lost when the existing structure is rubblized.

Concrete Overlay

Though there is no established procedure to design a concrete overlay of rubblized pavement, it is possible to use concepts from the AASHTO new concrete pavement and overlay design procedures to determine an overlay thickness.

The proposed procedure consists of designing the overlay as a new concrete pavement on an improved granular base with a higher k-value. This is the procedure used with concrete pavements on bases courses and concrete overlays of asphalt pavements (whitetopping). It also characterizes the rubblized pavement in the same manner as an asphalt overlay of a rubblized pavement.

Similar to the asphalt overlay, the key in the design procedure is to characterize the rubblized slab with an appropriate k-value. The following procedure is recommended:

1. Determine the rubblized slab modulus value (use the same procedure as used in the overlay design procedure for an asphalt overlay of a rubblized pavement).

2. Convert the rubblized slab modulus value to k-value using the procedures outlined in AASHTO Overlay Procedure for Concrete Overlays of Asphalt Pavements (whitetopping).

3. Design the overlay as a new pavement using the improved k-value determined in Step 2.

ACPA recommended layer coefficients values:

Rubblized Slab
0.14 - 0.25

Value depends on the future thickness or traffic requirements.

Lower values are appropriate for high traffic volumes, where thicknesses will be greater.

Higher values are appropriate for low traffic volumes, where thicknesses will be thinner.

Degradation or intrusion of fines into base course should also be taken into account. If there is degradation or intrusion of fines, then the lower values are appropriate.

Because of the wide variation of the modulus value, and because an exact value for a given project is impossible to determine until construction, it is recommended to use low values (i.e. 100,000 psi) until actual field and performance data provide better information.

SUMMARY

Rubblization is used to stop reflective cracking in asphalt overlays of existing concrete overlays. Though it is perceived as a rehabilitation technique, it is actually a destructive procedure that destroys the structure of the existing concrete slab and weakens the entire pavement system. Its use has been necessary because asphalt overlays are too weak to withstand the movements of the underlying concrete structure, resulting in reflective cracking and quick deterioration of the overlay.

Better alternatives to rubblization and asphalt overlays are concrete pavement restoration (CPR) and concrete overlays. These procedures directly address the cause of the pavement distress and keep the structural integrity of the pavement system intact.

Still, there are times when rubblization is an option for an existing concrete pavement. This occurs when the concrete slabs exhibit material problems such as alkali silica reactivity (ASR), D-cracking, or freeze-thaw damage. These materials problems cause the concrete pavement to deteriorate and lose its structural integrity.

Once a pavement is rubblized, it is viable to place either a concrete or an asphalt overlay. The advantage of the concrete overlay is that it is a long-term solution that will not need to be rehabilitated again for many, many years.

REFERENCES:

1. *Phone conversations with the South Carolina DOT, SC I-85 near Greenville SC.*

2. Guide Specifications for Highway Construction*, American Association of State Highway and Transportation Officials, Washington, DC, 1993*

3. *Michigan PMS data*

4. *Michigan Cost data*

5. *Rehabilitation of Jointed Portland Cement Concrete Pavement on I-35 (Southbound) in Kay County, Oklahoma,* J.F. Daleiden, D.a. Ooten, M.D. Sargernt, *Transportation Research Record 1513, .*

6. The Concrete Pavement Restoration Guide: Procedures for Preserving Concrete Pavements, *TB020P American Concrete Pavement Association, Skokie, IL, 1997.*

7. Diamond Grinding and CPR 2000*, TB008P, American Concrete Pavement Association, Skokie, IL, 1990.*

8. Guidelines for Full-Depth Repair, *TB002P, American Concrete Pavement Association, Skokie, IL, 1995.*

9. Guidelines for Partial-Depth Repair, *TB003P, American Concrete Pavement Association, Skokie, IL, 1989*.

10. Joint and Crack Sealing and Repair for Concrete Pavements, *TB012P, American Concrete Pavement Association, Skokie, IL, 1993.*

11. Slab Stabilization Guidelines for Concrete Pavements, *TB018P American Concrete Pavement Association, Skokie, IL, 1994.*

12. *NCHRP 204, Performance of Concrete Overlays*

13. Guidelines for Bonded Concrete Overlays, *TB007P, American Concrete Pavement Association, Skokie, IL, 1990*.

14. Guidelines for Unbonded Concrete Overlays, *TB005P, American Concrete Pavement Association, Skokie, IL, 1990*.

15. *Thompson, M.R., et al. HMA Overlay Construction with One Pass/lane-Width with PCCP Rubblization, Asphalt Paving Technology, Journal of the Association of Asphalt Paving Technologist, Vol. 66, 1997.*

16. *Presentation by Phillip Kirk, RMI given a the Southeastern Pavement Conference, Baton Rouge LA, .June 23, 1998*

17. *"AASHTO Guide for Design of Pavement Structures," American Association of State Highway and Transportation Officials, Washington D.C., 1993.*

18. *Structural Coefficients for Fractured Slabs,* Hall, K.T., Proyekta Ingenieria, Ltda. *paper prepared for the 1999 TRB Annual Meeting.*