Performance of a Rubblized Concrete Pavement on I-76

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The first concrete pavement in Colorado to be rehabilitated by rubblization was on I-76 in 1999. Resonant breaker, multi-head hammer and cracking and seating techniques were intended to fracture the concrete prior to asphalt overlay. Two of the rubblization methods were effective techniques for breaking the existing concrete pavement to create a base course for the new asphalt concrete overlay. However, some of the concrete slabs contained alkali silica reaction (ASR) and were badly cracked prior to rehabilitation. Although the presence of ASR did not require modification of the resonant breaker or multi-head hammer methods, it did preclude use of cracking and seating because the slabs could not be adequately fractured. The asphalt overlay has no distresses associated with reflective cracking from the old concrete pavement and has not demonstrated any settlement, permanent deformation or other distresses as a result of the rubblization processes seven years after construction. A falling-weight deflectometer was used to determine deflection in the pavement after five years service and indicated significant increases in asphalt modulus but no change in subgrade modulus. Moisture monitors indicate no accumulation of moisture in the rubblized concrete after five years.

Keywords: Pavement rubblization, pavement rehabilitation, concrete pavement, edge drains, alkali silica reaction

Background

The most common method of rehabilitating concrete pavements is by overlaying with asphalt concrete. The overlay process is a rapid technique, restores ride quality, and adds structure to the pavement section. A common side effect of this technique are reflection cracks which begin at each concrete joint and propagate through the asphalt overlay to the surface. The result is an asphalt pavement with longitudinal and transverse cracks located approximately over the original joints in the underlying concrete pavement. However, increasing the frequency of cracks in the concrete before overlaying reduces the strain at each crack, and therefore the chances for reflection cracking in the new overlay.

An experimental comparison of various methods of fracturing concrete pavement slabs was conducted in the early 1990s (Witczak and Rada 1992). Since then, destruction of concrete slabs has been done effectively by numerous agencies (Boyer 2000, Fitts 2001, Thompson 1999, Bemanian 1999, Ksaibati 1999, Galal 1999) on low and very high traffic facilities (Heckel 2002, Weinrank 2006). A national study conducted by the National Asphalt Pavement Association (NAPA 1994) provides an excellent review of most slab fracturing processes and effectiveness including the methods reported herein and summarized below.

Multi-Head Hammer

The Multi-Head Hammer has sixteen 1200 to 1500 pound drop hammers mounted laterally in pairs with half the hammers in a forward row and the remainder diagonally offset in a rear row. Each pair of hammers is attached to a hydraulic lift cylinder operating independently. Each pair of hammers develops between 1000 and 8000 foot-pounds of energy depending upon the lift height. The drop height of each pair of hammers can be adjusted during production to control the amount of breaking energy that is transferred to the pavement. The machine has twelve hammers measuring eight inches wide producing damage to the concrete from 2.67 to 13 feet wide.

Resonant Frequency Breaker

The Resonant Frequency Breaker is a self-propelled device that utilizes high frequency, low amplitude impacts with a force of 2000 pounds. The foot is located at the end of a pedestal that is attached to a beam and counter weight. The force applied to the pavement is achieved by vibrating the large steel beam connected to the foot. The foot is moved along the concrete surface at the front of the machine. The breaking principle is that low amplitude, high frequency; resonant energy is delivered to the concrete slab, resulting in high tension at the top. Since concrete has low tensile strength, the slab fractures on a shear plane through the pavement. The foot, beam size, operating frequency, loading pressure and speed of the machine can be varied. Breaking begins at the centerline and proceeds to the outside edge of the pavement. The breaking pattern is approximately 8 inches wide requiring approximately twenty passes to break a twelve foot wide lane. Maximum amplitude is approximately one inch to avoid disruption of base and prevent damage to underground structures and speed of the equipment is such to produce forty four blows per second. Wheel loads are 20,000 pounds with total weight of 60,000 to 70,000 pounds, therefore the fractured pavement, shoulder and subgrade must have adequate structure to support multiple passes.

Research Problem

This experiment was conducted to evaluate three concrete fracturing processes, the effectiveness of edge drains to prevent moisture accumulation in the broken concrete and the use of the falling weight deflectometer data to measure subgrade, rubblized concrete and asphalt concrete resilient modulii for use in structural design methods.

Project Site

The project is located on I-76 approximately 135 miles northeast of Denver. The original pavement was constructed in 1967 consisting of eight inches of jointed plain concrete pavement over two inches of emulsified asphalt treated base. The pavement was overlaid in 1995 with two inches of asphalt concrete as a future bond breaker for an unbonded portland cement concrete overlay. However, the concrete overlay was abandonned in favor of rubblizing the existing pavement and placing an asphalt concrete overlay on top. Advantages of this process to the concrete overlay originally planned included reduced time and the ability to keep the pavement open to traffic during construction.

The four-lane project is located in both the eastbound and westbound directions carrying an average annual daily traffic volume of 5477 vehicles with 6 percent single unit trucks and 25 percent combination trucks resulting in 6.5 million equivalent single axle loads over a 20-year design life.

Experiment Design

The experiment was designed with three methods of breaking the concrete pavement prior to overlay. These were rubblization by the resonant breaker and the multi-head hammer and cracking and seating. However, do to significant alkali-silica reactivity of the concrete pavement most of the slabs were badly deteriorated. Because of this, the cracking and seating technique was ineffective at transmitting enough energy to the slabs to fully break them. Therefore, the crack and seat technique was abandoned. Therefore, the experiment consists of four miles of pavement in the eastbound and westbound directions in both the driving and passing lanes, or sixteen lane-miles. Four lane-miles in each direction was treated with the resonant breaker and four lane-miles was treated with the multi head hammer.

Preconstruction

Pavement Section Design

There was limited experience to determine the structural section for the asphalt overlay on rubblized concrete prior to this experiment. Therefore, a review of the literature (Asphalt Institute 1998, National Asphalt Pavement Association 1994) for placing asphalt on concrete and rubblized concrete was considered. Parameters used to evaluate the design from the literature are shown in Table 1. This pavement section was obtained using a structural number of zero for the asphalt treated base under the concrete, and a broken concrete thickness of 8 inches. In addition to this analysis a falling weight deflectometer was used to evaluate deflection of the rubblized concrete. This data was used to back-calculate the resilient modulus of the subgrade and fractured concrete pavement as input into the DARWin pavement design program (AASHTO 1993) to obtain the information shown in Table 2.

Table 1: Parameters Used for Overlay Thickness Design

20-Year 18 kip ESALs, millions	6.5
Servicability Loss	2.0
Reliability, %	90
Standard Deviation	0.44
Strength Coefficient for Fractured JPCP (assumed)	0.25
Subgrade Resilient Modulus (assumed), 1000 psi	29
Overlay Thickness, in	6

Table 2: DARWin Pavement Design Results

Section	Structural Number Required	Existing Structural Number*	Overlay Thickness, in
Multihead Hammer, WB	3.41	2.00	3.2
Resonant Breaker, WB	3.47	2.00	3.3
Multihead Hammer, EB	3.01	2.00	2.3
Resonant Breaker, EB	3.49	2.00	3.4

* based on resilient modulus of subgrade from backcalculation

Although there was some difference between the overlay thickness obtained by conventional techniques and that from the falling weight deflectometer results, the six inch overlay was utilized to be conservative.

Construction

The project consisted of removing the two inches of asphalt pavement on top of the concrete by cold milling, installing edge drains, rubblizing the concrete pavement, reconditioning the shoulders, and placing six inches of new hot mix asphalt pavement across the full width of the pavement. Asphalt mix design followed Superpave specifications for gradation, design gyrations, and binder selection. Design gyrations were 109, and the nominal ¾ inch mix contained a 98 percent reliability PG 76-28 binder.

Multi-Head Hammer

The multi-head hammer fractured the existing concrete into pieces three inches or less in the top half of the pavement and nine inches or less in the bottom half of the pavement. Test pits were used to insure that the proper amount and size of fractured concrete was produced. Two test sections were installed using the multi-head hammer in the eastbound and westbound lanes from milepost 128.86 to 126.63. A 4-foot by 4-foot test section was excavated to visually inspect and verify that the multi-head hammer was producing the specified sizes.

A steel vibratory roller fitted with “Z” pattern grid on the drum face operating in the vibratory mode was used to seat the rubblized pavement.

Resonant Frequency Breaker

The resonant breaker was required to fracture the existing concrete to a nominal 1 to 3 inches in size. Two test sections were installed using the resonant breaker in the eastbound and westbound driving lanes from milepost 126.62 to 124.65. At the beginning of rubblization operations, a 4-foot by 4-foot test section was excavated to visually inspect the size of the rubblized concrete and insure the resonant breaker was producing the specified sizes.

Following the rubblization process and prior to placing the first asphalt lift, a smooth drum 10-

ton steel roller operating in the vibrating mode was used to seat the rubblized concrete.

Moisture Probes

Following rubblization, moisture probes were installed adjacent the rubblized concrete pavement to determine effectiveness of the edge drains. Probes were placed at the interface of the rubblized concrete and the base course.

Three locations within each research test section had moisture probes installed in the center of the driving lane, and one additional probe located one foot from the driving lane and shoulder joint. This location is near the edge drains and senses moisture draining through the rubblized concrete and edge drain system.

A tipping rain gauge was installed immediately adjacent the test sections. An electronic data logging apparatus was used to record hourly rainfall. This data used in connection with the moisture probes was collected monthly and analyzed to determine moisture content in the edge drains and judge effectiveness.

Asphalt Mixture Testing

French Rut Test and Hamburg Wheel Tracking

In addition to conventional mixture testing such as volumetric analysis, Hveem stability and moisture susceptibility tests, each mix used on this project was also tested using the French rut tester to determine resistance to plastic flow, and the Hamburg wheel tracking device to determine resistance to moisture damage and rutting (Aschenbrener and Stuart 1992).

Results from the French rut tester and Hamburg wheel tracking device are shown in Table 3 for test temperatures of 55C (131F) as determined by the climate in the project location and the type of binders utilized in the mixture (Aschenbrener 1992, Aschenbrener and Currier 1993).

Table 3: French Rut Test Results

AC Grade	Average French Rut Test Deformation*, %	Average Hamburg Deformation**, mm
PG 70-34	3.76	4.30
PG 76-28	3.00	2.08

*Passing test results equal deformation less than 10 percent.
**Passing test results equal deformation less than or equal to 10 mm

Performance

Evaluations were conducted after construction to evaluate cracking, rutting, moisture monitoring of the edge drains, and falling weight deflectometer testing.

Rutting

Rutting measurements were taken during annual evaluations. A six-foot straight edge was used to measure the rut depths in each wheel path of each lane. Measurements were taken at 50-foot intervals for the entire length of the 1000-foot test sections. Table 4 shows the average of the rut depths.

Table 4: Rutting Measurements

	WB Resonant Breaker, mm				WB Multi-head Hammer, mm			
	Driving Lane		Passing Lane		Driving Lane		Passing Lane	
	RWP	LWP	RWP	LWP	RWP	LWP	RWP	LWP
6-13-01	0.6	0.0	0.0	0.0	0.9	0.0	0.0	0.6
7-8-03	0.2	0.1	0.1	0.1	0.8	0.3	0.0	0.1
7-19-04	0.1	0.0	0.0	0.1	0.6	0.1	0.0	0.7

	EB Resonant Breaker				EB Multi-head Hammer			
	Driving Lane		Passing Lane		Driving Lane		Passing Lane	
	RWP	LWP	RWP	LWP	RWP	LWP	RWP	LWP
6-13-01	0.3	0.2	0.1	0.2	0.0	0.1	0.0	0.0
7-8-03	0.6	0.6	0.0	0.5	0.0	0.6	0.0	0.1
7-19-04	0.3	1.0	0.0	0.1	0.0	0.1	0.3	0.0

RWP = Right Wheel Path
LWP = Left Wheel Path

A maximum of 1 mm of rutting has occurred during the first five years service. This good performance correlates well with the results of the French rut tester and Hamburg wheel tracking device. Also, there appears to be a reduction in rutting over time for some sections. This is probably due to the imprecision in rut measuring techniques for rutting less than 1 mm in depth.

Cracking

Crack maps were updated with each annual evaluation to document the amount of cracking that occurred in the new asphalt pavement. A summary of the cracking history since construction is shown in Table 5.

The cracking appearing in the asphalt overlay has been identified as 'top-down' cracking, a phenomenon that has been associated with asphalt mixtures containing low asphalt content, low voids in the mineral aggregate or both. Although cracking has occurred it does not appear to be due to reflection of joints or previous cracks in the concrete, but new cracks due to the mixture properties. While this cracking is not desirable, it does not appear to be related to the rubblization process and it is believed reflection cracking from the longitudinal and transverse concrete joint slabs would have been significantly more extensive had the rubblization process not been utilized.

Table 5: Cracking Performance, linear feet

	WB Resonant Breaker		WB Multi-head Hammer	
Date	Longitudinal	Transverse	Longitudinal	Transverse
6-13-01	0	10	27	11
7-8-03	64	10	110	11
7-19-04	106	10	168	11

	EB Resonant Breaker		EB Multi-head Hammer	
	Longitudinal	Transverse	Longitudinal	Transverse
6-13-01	3	0	0	0
7-8-03	65	0	96	0
7-19-04	146	0	207	8

Ravelling

Ravelling is occurring in approximately 60 percent of the westbound and 25 percent of the eastbound lanes. The loss of fines was first noted in the 2002 field notes and has become a maintenance problem. The loss of fine aggregate on this pavement supports the need for a wearing course relatively early in the life of a new pavement to protect the structural lower layers, and extend the useful life of a pavement. Both mixes used on this project passed all of the moisture susceptibility tests as well as the Hamburg Wheel Tracking tests indicating these tests may not provide all the information needed to identify potential moisture damage.

Falling Weight Deflectometer (FWD)

FWD measurements indicated load transfer of the old concrete slabs was very acceptable. Load transfer ranged from 83 to 95 percent. This indicates a very good load transfer mechanism. After rubblization, FWD deflections indicated load transfer from 64 to 69 percent with the exception of one multi-head hammer section with a load transfer of 45 percent. This section received two passes using the multi-head hammer. Load transfer measurements of less than 50 percent are indicative of complete fracture.

One factor to be determined in this experiment was whether less than 50 percent load transfer was needed for a successful rubblization project. Based on the cracking data shown in Table 5, there is no significant difference in the amount of cracking in any of the test sections indicating that load transfer up to 69 percent is adequate to prevent crack reflection in the overlay.

FWD measurements were taken during construction for each lift of the new pavement and on top the rubblized PCCP. Subgrade resilient modulus and effective pavement modulus were determined by back-calculation. These subgrade and pavement modulii are shown in Figures 1 and 2, respectively, immediately after construction in 1999, and in 2004.

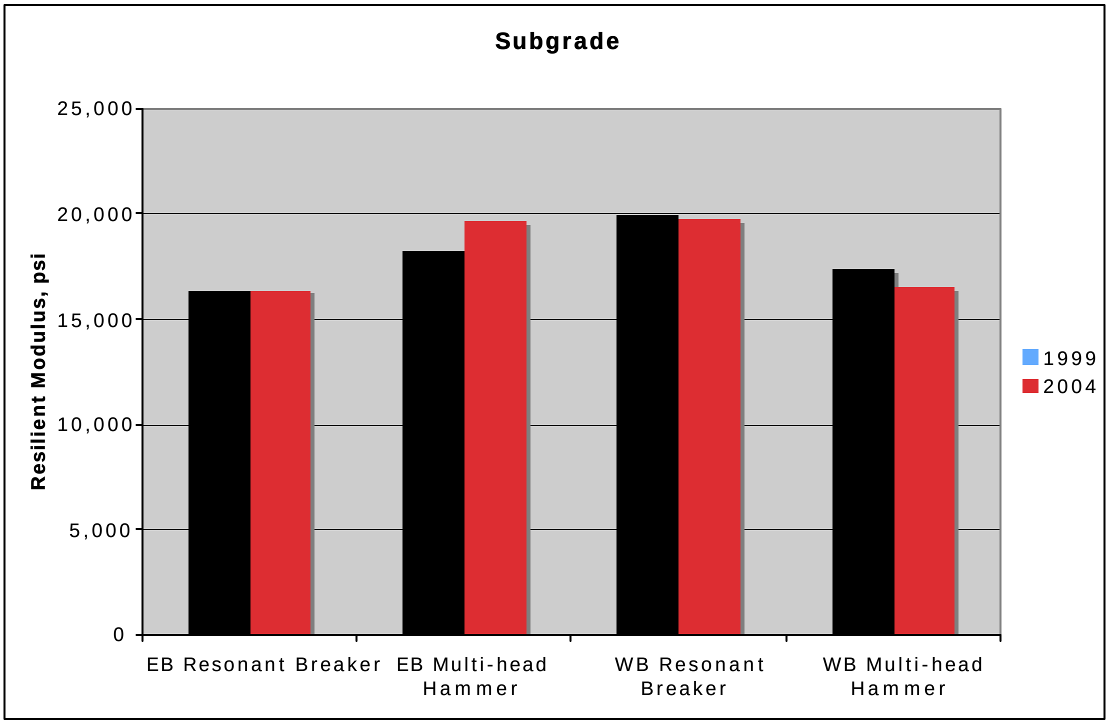

Figure 1: Subgrade Resilient Modulus for Various Sections

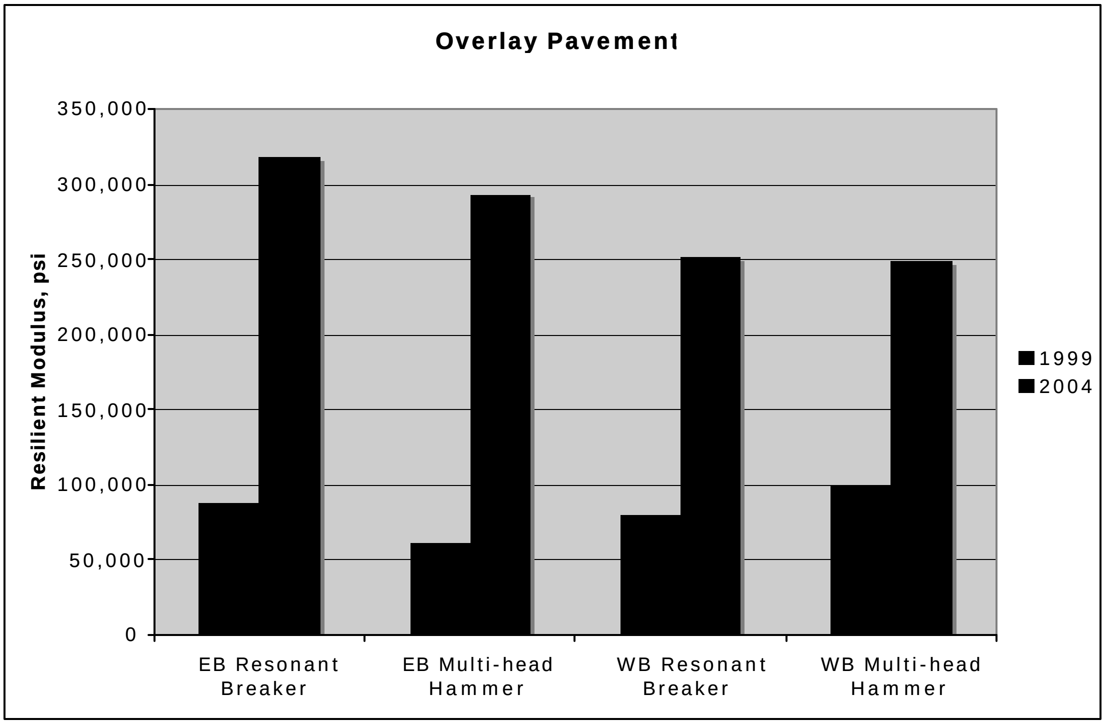

Figure 2: Overlay Pavement Resilient Modulus for Various Sections

The subgrade modulus has not significantly changed from 1999 until 2004 according to the FWD deflections indicating the method of rubblization does not affect this property.

However, the pavement modulus has increased significantly from original construction in 1999 until 2004. This increase in pavement modulus may be due to a combination of cementing of the rubblized concrete and stiffening of the asphalt pavement due to oxidation. Both eastbound sections have approximately the same pavement modulus as do the westbound sections. This indicates no significant difference on concrete destruction with respect to rubblization method and may be an indication of the uniformity of original construction.

Edge Drains

When soils below a concrete pavement are not free draining, there is potential for the rubblized concrete to hold water which can result in pumping. Because of this potential, edge drains are recommended whenever rubblization of concrete pavements is done. Although the subgrade soil on this project is a relatively free draining A-3 sand, and the climate of the project is low precipitation of less than 15 inches annually edge drains were included. Measurements have been taken continuously since construction to monitor the moisture under the pavement. Measurements indicate somewhat higher moisture at the mid-lane location with progressively lower values with increasing depth, as would be expected. The moisture values were relatively constant after initial construction, and the values tend to confirm that moisture is migrating from the lane interior toward the edge drain, indicating the drainage system is working. Visual observation of the drain outlets showed that only after intense rainfall could the presence of water be observed at the drain outlets.

Conclusions

1. Rubblization of a plain, jointed concrete pavement followed by a hot mix asphalt overlay was demonstrated in this experiment as a successful rehabilitation method.

2. The resonant breaker and multi-head hammer rubblization methods performed satisfactorily to fracture the concrete pavement and provide a suitable base for the asphalt overlay.

3. Cracking and seating of the concrete was not effective on slabs containing significant alkali silica reaction and was abandonned.

4. Edge drains were shown to be effective in preventing moisture from accumulating under the rubblized concrete and are recommended with rubblization unless the subgrade below the concrete can be shown to be free draining.

5. There was a significant difference between the overlay thickness determined using conventional design techniques and that determined using the back calculation of modulii method. This was evidently due to the higher modulus for the rubblized concrete obtained by back calculation than was assumed for the conventional pavement design method. As more experience is gained using the FWD to obtain back calculated modulii, revisions in the structural coefficients for pavement materials may be justified.

6. Top-down cracking occurred in the pavement after five years service. Although this distress is not believed related to the rubblization process, changes in the asphalt mixture design process may be warranted to reduce the potential of these cracks in the future.

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