Breaking and Seating of Rigid Pavements

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Breaking and seating have been used extensively in Kentucky to rehabilitate portland cement concrete pavements. Experience over 3 or 4 yr with this type of design and construction is summarized and reported. Breaking to a range of nominal fragments is evaluated, and a report on the evaluation of two roller weights for seating is given. Also described is the use of dynamic deflections to gauge the effectiveness of the breaking and seating process and to measure the appropriateness of the asphaltic concrete overlay.

Rigid (portland cement concrete) pavements are deteriorating rapidly in many areas of the country. Spalling, cracking, joint deterioration, and faulting at joints and cracks are common and lead to deteriorating ride quality and safety as well as increasing maintenance costs. Joint repairs or full-scale replacement result in significant capital expenditures and lengthy delays for travelers.

Two techniques used for rehabilitating rigid pavements are recycling and overlaying. Recycling may be done at a central plant or may be carried out in place. Centralized recycling typically involves pulverizing the existing concrete pavement, removing the fragmented material, processing the material (crushing, grading, removing steel, stock piling), and using all or a portion of the material as aggregate in a new concrete or hot-mix asphalt mixture. In-place recycling consists of converting the existing concrete pavement to a base and then overlaying it with either asphaltic concrete or portland cement concrete.

Reflection cracking of existing cracks and joints of the underlying pavement is a major problem when asphaltic concrete overlays are used over unbroken rigid pavements. Techniques employed specifically to reduce or prevent reflection cracking have not been completely successful. Procedures currently receiving attention include (a) breaking and seating the existing concrete pavement followed by placement of a relatively thick (more than 4 in.) asphaltic concrete overlay and (b) placement of a crack-relief layer followed by a moderately thick overlay (less than 4 in.) of asphaltic concrete.

A typical crack-relief layer consists of 3 to 4 in. of open-graded bituminous material placed over an existing rigid pavement. Another 3 to 4 in. of asphaltic concrete base and surface typically are placed over the crack-relief layer (*1*).

In-place recycling of rigid pavements has become popular in Kentucky in recent years. Specific methods have varied but generally consist of breaking and seating the rigid pavement followed by overlaying with asphaltic concrete. Nominal sizes of fragments vary from $^1/_2 \times 3$ ft to 4×6 ft, and overlay thicknesses used nationally range from $2^3/_4$ in. to $7^3/_4$ in. Prices for breaking and seating have varied from \$0.25/yd^2 to \$2.00 or more/yd^2 (*1–3*).

Types of breaking devices include a pile driver with a modified shoe, a transverse drop-bar (guillotine) hammer, a whip hammer, an impact hammer, and a resonant pavement breaker. There are also many different methods of seating broken concrete particles. Roller sizes have varied from 44,000 lb to 100,000 lb (*1*). Pneumatic-tired rollers weighing 30 to 50 tons are more commonly used, although there has been some experimentation with vibratory rollers of the steel-wheeled and sheepsfoot varieties.

BREAKING AND SEATING IN KENTUCKY

Kentucky has embarked on an extensive breaking and seating program to rehabilitate deteriorated portland cement concrete pavements. Between 1982 and 1986, over 750 lane-miles of pavement have been broken, seated, and overlaid with asphaltic concrete. Performance has been good; as a result, the practice continues routinely.

Road Rater deflection measurements have been obtained for a number of pavement sections before breaking, after breaking but before seating, at various stages during seating, after seating, and periodically after overlaying. Additionally, deflection measurements have been obtained at various phases of the seating activities for both 50-ton and 35-ton pneumatic rollers. A detailed visual survey has been conducted for a number of sections. Findings of these evaluations will be summarized in this paper. These data will contribute to evaluation of the long-term performance of these pavements and of the effectiveness of breaking and seating procedures. Additionally, these data will be helpful in the development of rational techniques for determining overlay thickness requirements over broken and seated pavements. Currently, Kentucky thickness design determinations are based on the assumption that the broken portland cement concrete will perform in the same manner as a conventional dense-graded aggregate base. The validity of this assumption needs to be determined.

Breaking Patterns

The condition of the existing rigid pavement may significantly influence the manner in which a pavement will fracture. The

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resultant breaking pattern apparently is a function of the energy absorbed by the slab and the way in which the energy is dissipated throughout the slab and pavement structure. Dissipation of energy is dependent on the strength and thickness of the existing concrete, joint and crack spacing and condition, and degree of deterioration of the slab. Other factors may include temperature and time of day, which may affect the extent and degree of curling and warping that may alter resulting pavement cracking patterns. For example, peculiar pavement breaking patterns (longitudinal fracturing resulting in a series of "beams") have been observed during extended periods of high temperature. High temperatures may result in excessive compressive stresses at joints, which then may alter pavement breaking characteristics.

The appropriate nominal size of fragmentation remains controversial. The size of fragments has a direct impact on design considerations as well as on the long-term performance of the overlay. Small fragments will most certainly reduce and possibly eliminate reflective cracking in the asphaltic concrete overlay but use the least structural potential of the existing portland cement concrete pavement. Conversely, very large fragments may maximize the structural potential of the existing portland cement concrete but may be large enough to permit thermal movements of the existing pieces and thereby maintain the potential for reflective cracking. Large fragments may also have more potential for rocking as a result of ineffective seating and may therefore increase the potential for cracking of the overlay. Research in Kentucky has involved three ranges of nominal fragment sizes for cracked concrete:

1. 3 to 12 in.,
2. 18 to 24 in., and
3. 30 to 36 in.

Current Kentucky specifications (*4*) require pavements to be broken to a nominal 24-in. size and permit up to 20 percent of the fragments to exceed 24 in. Pieces larger than 30 in. are not permitted. Research is continuing to determine the optimum size for fragmenting portland cement concrete pavements. No definite conclusions appear to have been reached at this time. Experience in Kentucky generally favors the 18- to 24-in. fragments.

Current specifications require viewing fragmentation patterns of a dry surface (*4*). There is also no uniform procedure to determine whether a broken slab meets required specifications. Two procedures have been used to evaluate the extent of breaking:

1. Visual evaluation by counting the number of particles and measuring the maximum dimensions of the largest particles, and
2. Comparison of deflection measurements before and after breaking using a Road Rater.

Visual evaluations are more readily adaptable to capabilities of construction inspection personnel but are subject to controversy because of subjectivity. They are used routinely for acceptance or rejection of the breaking pattern. Deflection testing has been used only for verification of the effectiveness of breaking and seating. Early Kentucky plan notes allowed the cracking pattern to be viewed by wetting the pavement surface. Wetting the surface presented inspection problems because it is not practical to continually wet the surface for viewing the cracking pattern. Some cracking may be observed without the aid of a wetted surface and is dependent on the characteristics of the unbroken slab, equipment used to break and seat, and condition of underlying layers. Current special provisions (*4*) require the broken pavement to be viewed without the aid of a wetted surface.

Deflection testing provides a more objective and definitive comparison of before-and-after conditions. The principal problem associated with deflection testing for acceptance or rejection is the availability of deflection testing equipment for construction personnel and the level of experience and expertise required to collect and interpret deflection measurements.

Breaking Equipment

Three types of pavement breakers have been used in Kentucky: (a) pile-driving hammer, (b) transverse-bar drop hammer (guillotine), and (c) whip hammer. The pile-driving hammer and the whip hammer typically result in longitudinal and diagonal cracking, whereas the transverse-bar drop hammer typically produces transverse cracking of the existing portland cement concrete pavement.

The most common pavement breaker currently in use in Kentucky is the modified diesel pile-driving hammer. The hammer typically is mounted in a rolling carriage and is towed by a tractor. The force or energy of impact may be changed by throttling the flow of fuel to the hammer. The greater the fuel input to the hammer, the greater the force applied to the pavement. Generally the firing rate for a hammer remains constant. As such, the number of blows applied to the pavement may be modified by varying the speed of the towing vehicle.

The breaking pattern is a function of the energy applied to the pavement slab. One method of "measuring" the energy input is to determine the total number of blows applied to the pavement at a constant force or impact level for the hammer. Experience in Kentucky has shown that 18- to 24-in. fragments may be achieved when the pile-driving hammer traverses a slab with three or four passes per lane width equally spaced transversely across the slab and the interval between impact blows of the hammer is 12 to 18 in. The transverse spacing of passes, interval between impact blows, number of passes, and hammer throttle setting are functions of the condition and thickness of the existing portland cement concrete and the quality of the subgrade. The throttle setting for a pile-driving hammer should be at a level sufficient to fracture the pavement yet not so large as to create punching and deep indentations.

Additional experience in Kentucky has indicated that fragment sizes of 30 to 36 in. may be achieved with two or three passes of a pile hammer at an interval of 12 to 18 in. between impact blows. Similarly, fragments of 3 to 12 in. may result from seven to eight passes and the same 12- to 18-in. interval between impact blows.

One other factor affecting the breaking pattern when using the pile-driving hammer is the shape of the head or "shoe" that strikes the pavement. Breakers used in Kentucky typically have a plate type of shoe to prevent or minimize penetration or

punching into the surface of the existing portland cement concrete pavement. The most effective shoe is apparently a square (on the order of 18 in. square) rotated 45 degrees to the direction of travel. This shape apparently contributes to diagonal breaking interconnected with longitudinal cracks to form the desired pattern.

The whip hammer consists of an impact hammer attached to the end of a leaf-spring arm. The whip hammer may be moved in the horizontal as well as the vertical direction. The impact force is developed by the whipping action of the leaf-spring arm and hammer head. The energy is transmitted to the pavement by a base plate or shoe in much the same manner as that noted with the pile-driving hammer. Typically, the plate will have a diamond, square, or rectangular shape. The whip hammer typically is mounted on the rear of a truck and usually is equipped with dual controls, permitting use by only one operator.

The force developed by the whip hammer is apparently a function of the pressure in the hydraulic system and the resiliency and number of leaf springs supporting the hammer head. As is seen with the pile-driving hammer, the resulting cracking pattern is a function of the total number of blows applied to the pavement. Blows from the whip hammer typically are applied in a more random manner than they are for the pile-driving hammer. This provides for greater potential of a random cracking pattern but at the same time makes it more difficult to input a consistent level of impact energy. The whip hammer may be maneuvered in an arc, typically providing a coverage of approximately an 8-ft arc. An 18- to 24-in. breaking pattern may usually be achieved with one blow of the whip hammer per square foot of pavement surface area. The whip hammer has not yet been used in Kentucky to break rigid pavement to other sizes. As noted with the pile-driving hammer, the specific fragment size will vary from pavement section to pavement section.

The transverse drop-bar (guillotine) hammer has been used to break one section (approximately 50 lane-miles) of concrete pavement in Kentucky. The drop bar (blade) typically weighs 5 to 7 tons and the drop is usually 18 in. The operator varies the speed of travel and thereby controls the interval between impacts. The force of impact may be varied by changing the height of the drop (*1, 2*).

Seating

Seating the fragments is necessary to ensure a stable foundation for the asphaltic concrete overlay. With inadequate seating, individual fragments tend to rock, increasing the potential for reflection cracking. With pavement breaking, seating requirements and characteristics may vary with fragment size, quality, and characteristics of the existing pavement and quality of the subgrade.

The objective of seating is to place all fragments in contact with the supporting aggregate base or subgrade. Experience so far has indicated that the most efficient seating of a broken portland cement concrete pavement may be accomplished by rolling with a heavy pneumatic-tired roller. Typical roller sizes vary from 30 to 50 tons. Steel-wheeled (static and vibratory) rollers have been used but have not been fully effective because of bridging over fragments. An 8-ton steel-wheeled vibratory roller was specified for the first project in Kentucky but this roller proved inadequate. Roller requirements were modified by a construction change order to use a 30-ton pneumatic-tired roller. Subsequent projects required seating by a 50-ton pneumatic-tired roller. Recent evaluations, however, have indicated that the 30-ton pneumatic-tired roller is almost as effective. Currently, a 30-ton pneumatic-tired roller is the smallest roller permitted.

EVALUATIONS

Effectiveness of Breaking

A simplified technique has been used for evaluating deflections obtained before, during, and after breaking portland cement concrete pavement as well as after paving. Examples of deflections of two pavements are presented in Tables 1 and 2. The tables present average field measured deflections as well as theoretically simulated deflections and associated layer moduli.

Field data in Tables 1 and 2 were used to determine information presented in Table 3, which summarizes ratios of deflections after breaking (but before overlaying) to deflections before breaking. The ratios also are summarized in Figure 1. There appears to be a relationship among fragment size, effective stiffness modulus, and ratio of deflections (after breaking to before breaking).

Effectiveness of Seating

Deflection measurements were obtained before breaking and after various intervals during rolling with the 30-ton roller used for the first Kentucky project and for a 35-ton and 50-ton roller for a subsequent project. Results of the latter evaluation are summarized in Figures 2, 3, and 4. Data from three locations (midslab, opposing third points, and opposing edges or corners) are presented. The average deflections shown are for all slabs tested and for all four Road Rater sensors. Initially, average deflection curves were plotted for each sensor, but the similarity of the curves suggested that they could be combined into the average curves shown. Data indicate the following general trends:

1. An increase in deflections after initial roller passes,
2. A reduction or stabilization of deflections with additional roller passes, and
3. An increase in deflections with a large number of roller passes.

At the midslab and third-point locations, the two rollers had similar average deflections, with the 35-ton roller actually giving more consistent values. At the edges, however, the 35-ton roller did not appear to seat the broken pavement as well as did the 50-ton roller. This is not surprising, because the 35-ton roller was not as wide as the 50-ton roller. In the comparison study, both rollers were used along the centerline of the lane. It appears that, for the smaller roller, special efforts must be made to ensure seating at the edges.

In California (*1, 2*), a vibratory sheepsfoot roller weighing 44,000 lb was used. Ten rolling passes were applied in each half of a 12-ft lane. The roller width of 8 ft resulted in

TABLE 1 SUMMARY OF ANALYSES OF DEFLECTION MEASUREMENTS: I–64, JEFFERSON AND SHELBY COUNTIES

										THEORETICAL DEFLECTIONS									
										STIFFNESS MODULI (KSI)									
				TERMINI		FIELD DEFLECTIONS[a] (INCHES X 10^{-5})				ASPHALTIC CONCRETE						THEORETICAL DEFLECTIONS (INCHES X 10^{-5})			
PARTICLE SIZE (INCHES)	TEST DATE	SURFACE TEMP. °F	DIREC-TION	BEGIN MP	END MP	NO.1	NO.2	NO.3	NO.4	0.5 HZ[b] LOADING	25 HZ[c] LOADING	PCC UNBROKEN	PCC CRACK/SEAT	CRUSHED STONE	SUBGRADE	NO.1	NO.2	NO.3	NO.2
*	12/03/82	75	WEST	19.0	31.7	22.8	20.2	12.2	10.6			4,000		45.0	18.0	22.8	20.4	18.0	15.6
*	12/03/82	75	WEST	19.0	31.7	22.8	20.2	12.2	10.6			6,000		32.8	12.0	21.0	18.5	16.7	14.7
*	12/03/82	75	WEST	19.0	31.7	22.8	20.2	12.2	10.6			6,000		46.2	18.0	20.2	17.5	15.9	14.1
30-36	7/20/83		WEST	20.6	22.3	52.2	45.7	32.1	26.1				1,000	29.4	10.5	49.0	44.1	36.7	29.9
18-24	7/20/83		WEST	30.8	31.7	57.0	51.3	35.0	29.6				500	29.4	10.5	59.8	51.6	40.6	31.4
18-24	7/20/83		WEST	30.8	31.7	57.0	51.3	35.0	29.6				1,000	29.4	10.5	49.0	44.1	36.7	29.9
18-24	7/20/83		WEST	30.8	31.7	68.6	55.9	40.6	29.6				200	29.4	10.5	77.8	60.9	43.9	31.9
6-12	7/20/83		WEST	19.0	20.6	226.3	158.5	80.7	48.3				25	23.1	7.5	177.7	102.4	64.2	43.4
6-12	10/31/83	80	EAST	19.0	20.6	141.4	101.2	54.4	32.7				25	29.4	10.5	144.9	75.8	46.0	30.7
6-12	10/31/83	80	EAST	19.0	20.6	141.4	101.2	54.4	32.7				50	23.1	7.5	143.6	96.2	63.6	43.9
30-36	11/01/83	80	EAST	20.6	22.3	57.9	46.8	32.4	23.0				100	41.5	16.5	69.1	45.2	29.1	19.9
30-36	11/01/83	80	EAST	20.6	22.3	57.9	46.8	32.4	23.0				200	41.5	16.5	56.8	41.8	28.7	20.2
30-36	8/01/85	68	EAST	20.7	21.9	20.9	15.6	11.6	8.8	1,200	2,200		2,000	41.6	16.5	19.1	15.6	14.7	13.4
30-36	8/01/85	68	EAST	20.7	21.9	20.9	15.6	11.6	8.9	1,850	2,700		1,000	41.6	16.5	20.8	17.3	15.9	14.3
6-12	8/01/85	68	EAST	19.0	20.6	32.5	23.9	16.4	12.4	1,850	2,700		200	41.6	16.5	26.3	23.0	19.8	16.9
6-12	8/01/85	68	EAST	19.0	20.6	32.5	23.9	16.4	12.4	1,850	2,700		100	41.6	16.5	28.4	25.1	21.2	17.6
6-12	9/25/85	57	EAST	18.8	20.6	31.7	23.4	16.9	13.2	730	1,700		200	41.6	16.5	28.2	24.3	20.6	17.2
18-24	9/25/85	57	EAST	23.3	25.5	20.5	14.4	11.8	10.9	1,850	2,700		1,000	41.6	16.5	20.8	17.3	15.9	14.3
18-24	9/25/85	57	EAST	23.3	25.5	20.5	14.4	11.8	10.9	1,200	2,200		2,000	41.6	16.5	19.1	15.6	14.7	13.4
18-24	9/25/85	63	EAST	30.8	31.8	36.1	27.7	20.5	16.0	1,200	1,200		200	41.6	16.5	34.2	28.4	22.7	18.3
18-24	9/25/85	63	EAST	30.8	31.8	36.1	27.7	20.5	16.0	730	1,700		200	41.6	16.5	32.9	27.8	22.4	18.2
18-24	9/25/85	63	EAST	30.8	31.8	36.1	27.7	20.5	16.0	240	800		200	41.6	16.5	35.7	29.2	23.2	18.6

* UNBROKEN PAVEMENT
[a] MODEL 400B ROAD RATER
DYNAMIC LOAD = 600 lbf
STATIC LOAD = 1670 lbf
25 HZ FREQUENCY
0.06 INCHES AMPLITUDE OF VIBRATION
[b] ELASTIC STIFFNESS AT 0.5 HZ FREQUENCY OF LOADING AND PREVAILING TEMPERATURE
[c] ELASTIC STIFFNESS AT 25 HZ FREQUENCY OF LOADING AND PREVAILING TEMPERATURE
SENSOR POSITIONS:
NO.1 5.25 INCHES FROM LOAD FEET
NO.2 13.10 INCHES FROM LOAD FEET
NO.3 24.57 INCHES FROM LOAD FEET
NO.4 36.38 INCHES FROM LOAD FEET

overlapping of the middle 4 ft and double rolling for that specific area. Deflection measurements after seating were typically greater than those before seating. It was conjectured that overworking of the cracked areas caused a loosening effect.

Kentucky experience with deflection testing before, during, and after seating is summarized in Figures 2, 3, and 4. It has been conjectured that the initial reduction and stabilization of deflections represent initial seating of the cracked concrete pavement. The increase in deflections to levels greater than those before seating generally supports observations elsewhere.

These observations are the subject for some concern about seating requirements. Failure to achieve proper seating might result in premature and potentially damaging cracks within the asphaltic concrete overlay as the result of rocking of fragments of portland cement concrete. Conversely, overrolling may cause the existing portland cement concrete pavement to become unbonded from the temperature reinforcement steel or to destroy interlock between individual fragments, or both. There is also concern that traffic will eventually overroll the concrete slab, resulting in premature failure of the asphaltic concrete overlay.

Practicality tends to dictate use of heavy rollers and a minimum number of passes as opposed to a greater number of passes of lighter rollers. Use of heavy rollers (50 tons or greater) may overload bridges and be less maneuverable in close confines. Lighter rollers generally may require more passes to achieve effective seating, but the added maneuverability permits more uniform coverage of the pavement.

Considering experience in Kentucky and elsewhere (*1, 2, 5–7*) and results of deflection measurements, it is recommended that the minimum-sized roller for seating be 35 tons. Multitired pneumatic rollers are recommended in place of two-tired rollers, when possible. At least five passes of a 35-ton pneumatic-tired roller are recommended, with a staggered (overlapping) pattern to ensure adequate seating at the edges. Three passes of a 50-ton pneumatic-tired roller are also a permissible minimum. It should be emphasized that current data do not indicate the equivalency of the stated coverages for each roller size. Instead, the stated coverages are generally optimum on the basis of minimum number of passes (within the limits of practical construction procedures) for each roller size relative to the magnitude of deflection after rolling.

Short-Term Performance

The oldest in-service section of broken and seated portland cement concrete overlaid with asphaltic concrete was completed in October 1983. None of the pavement sections has been subjected to an accumulation of fatigue [18-kip equivalent axle loads (EALs)] necessary for the manifestation of visual surface distresses.

Reflection cracking of the asphaltic concrete overlay, although not specifically associated with structural deterioration,

TABLE 2 SUMMARY OF ANALYSES OF DEFLECTION MEASUREMENTS: I–71, GALLATIN COUNTY

PARTICLE SIZE (INCHES)	TEST DATE	SURFACE TEMP. °F	DIREC-TION	TERMINI BEGIN MP	TERMINI END MP	FIELD DEFLECTIONS[a] (INCHES X 10^{-5}) NO.1	NO.2	NO.3	NO.4	THEORETICAL DEFLECTIONS: STIFFNESS MODULI (KSI): ASPHALTIC CONCRETE 0.5 HZ[b] LOADING	ASPHALTIC CONCRETE 25 HZ[c] LOADING	PCC UNBROKEN	PCC CRACK/SEAT	CRUSHED STONE	SUBGRADE	THEORETICAL DEFLECTIONS (INCHES X 10^{-5}) NO.1	NO.2	NO.3	NO.2
*	6/17/82	83	SOUTH	56.67	57.91	24.3	21.5	17.8	11.1			4,000		45.9	18.0	23.2	20.8	18.4	15.8
*	6/17/82	89	SOUTH	58.95	59.90	13.9	17.6	12.4	9.5			4,000		70.0	30.0	15.9	14.4	12.3	10.2
*	6/17/82	89	SOUTH	59.99	69.82	20.4	21.9	17.5	11.9			6,000		46.2	18.0	21.0	18.5	16.7	14.7
*	6/17/82	93	NORTH	56.67	69.82	22.5	22.5	17.8	13.2			4,000		45.9	18.0	23.2	20.8	18.4	15.8
3-6	6/ /82		SOUTH	57.89	58.89	144.3	98.3	46.4	25.2				25	29.4	10.5	144.9	75.8	46.0	30.7
3-6	6/ /82		SOUTH	57.89	58.89	144.3	98.3	46.4	25.2				50	23.1	7.5	143.6	96.2	63.6	44.0
18-24	6/ /82					51.1	56.9	39.6	28.2				500	29.4	10.5	59.8	51.6	40.6	31.4
18-24	6/ /82					51.1	56.9	39.6	28.2				1,000	29.4	10.5	49.0	44.1	36.7	29.9
30-36	6/ /82		SOUTH	58.89	59.89	31.3	29.5	19.8	12.0				2,000	41.6	16.5	29.3	26.5	22.5	18.6
30-36	6/ /82		SOUTH	58.89	59.89	31.3	29.5	19.8	12.0				1,000	41.6	16.5	35.7	31.3	25.1	19.8
*	9/13/83	87	SOUTH	56.67	57.91	23.5	17.6	12.2	8.1	428	1,200		2,000	41.6	16.5	20.7	17.1	15.8	14.3
*	9/13/83	87	SOUTH	56.67	57.91	23.5	17.6	12.2	8.1	127	500		2,000	41.6	16.5	23.2	19.4	17.7	15.7
3-12	9/13/83	87	SOUTH	58.00	58.90	34.0	26.5	16.1	13.8	239	800		100	41.6	16.5	35.4	29.4	23.1	18.4
3-12	9/13/83	87	SOUTH	58.00	58.90	34.0	26.5	16.1	13.8	127	500		200	29.4	10.5	33.2	27.3	22.2	18.1
18-24	9/13/83	92	SOUTH	60.00	69.40	26.2	21.2	13.7	10.6	239	800		500	41.6	16.5	26.5	22.5	19.5	16.7
18-24	9/13/83	92	SOUTH	60.00	69.40	26.2	21.2	13.7	10.6	64	300		1,000	41.6	16.5	27.3	22.8	20.1	17.2
30-36	9/13/83	87	SOUTH	59.00	59.90	26.7	22.3	15.1	11.4	239	800		500	41.6	16.5	26.5	22.5	19.5	16.7
30-36	9/13/83	87	SOUTH	59.00	59.90	26.7	22.3	15.1	11.4	64	300		1,000	41.6	16.5	27.3	22.8	20.1	17.2
18-24	9/13/83	94	NORTH	56.67	69.60	30.6	23.0	16.0	12.3	64	300		500	41.6	16.5	30.2	25.0	21.3	17.8
18-24	9/13/83	94	NORTH	56.67	69.60	30.6	23.0	16.0	12.3	239	800		200	41.6	16.5	31.2	26.2	21.6	17.8
*	6/20/85	79	SOUTH	56.60	57.90	21.6	16.4	12.6	10.4	239	800		2,000	41.6	16.5	21.8	18.1	16.7	15.0
*	6/20/85	79	SOUTH	56.60	57.90	21.6	16.4	12.6	10.4	428	1,200		2,000	41.6	16.5	20.7	17.1	15.9	14.3
3-12	6/20/85	72	SOUTH	58.00	58.90	27.1	21.1	16.8	13.5	239	800		500	41.6	16.5	26.5	22.5	19.5	16.7
3-12	6/20/85	72	SOUTH	58.00	58.90	27.1	21.1	16.8	13.5	428	1,200		500	41.6	16.5	25.3	21.5	18.8	16.3
18-24	6/20/85	72	SOUTH	60.00	69.40	20.7	16.2	12.8	10.2	239	800		2,000	41.6	16.5	21.8	18.1	16.7	15.0
18-24	6/20/85	72	SOUTH	60.00	69.40	20.7	16.2	12.8	10.2	428	1,200		2,000	41.6	16.5	20.7	17.1	15.9	14.3
30-36	6/20/85	72	SOUTH	59.00	59.90	20.1	15.8	13.9	11.7	239	800		2,000	41.6	16.5	21.8	18.1	16.7	15.0
30-36	6/20/85	72	SOUTH	59.00	59.90	20.1	15.8	13.9	11.7	428	1,200		2,000	41.6	16.5	20.7	17.1	15.9	14.3
18-24	6/20/85	87	NORTH	56.67	69.60	25.2	20.2	16.1	12.1	127	500		1,000	41.6	16.5	25.4	21.4	19.0	16.5
18-24	6/20/85	87	NORTH	56.67	69.60	25.2	20.2	16.1	12.1	239	800		500	41.6	16.5	26.5	22.5	19.5	16.7

* UNBROKEN PAVEMENT

[a] MODEL 400B ROAD RATER
DYNAMIC LOAD = 600 lbf
STATIC LOAD = 1670 lbf
25 HZ FREQUENCY
0.06 INCHES AMPLITUDE OF VIBRATION

[b] ELASTIC STIFFNESS AT 0.5 HZ FREQUENCY OF LOADING AND PREVAILING TEMPERATURE

[c] ELASTIC STIFFNESS AT 25 HZ FREQUENCY OF LOADING AND PREVAILING TEMPERATURE

SENSOR POSITIONS:
NO.1 5.25 INCHES FROM LOAD FEET
NO.2 13.10 INCHES FROM LOAD FEET
NO.3 24.57 INCHES FROM LOAD FEET
NO.4 36.38 INCHES FROM LOAD FEET

TABLE 3 RATIOS OF DEFLECTIONS: AFTER BREAKING AND BEFORE BREAKING

Route	Termini	Direction	Particle Size	Date	Ratios: Sensor No. 1	No. 2	No. 3	No. 4	Avg.
I–64	20.6–22.3	West	30–36	7/20/83	2.29	2.26	2.63	2.46	2.41
I–64	30.8–31.7	West	18–24	7/20/83	2.50	2.54	2.87	2.79	2.68
I–64	30.8–31.7	West	18–24	7/20/83	3.01	2.77	3.33	2.79	2.98
I–64	19.0–20.6	West	6–12	7/20/83	9.93	7.85	6.61	4.56	7.24
I–64	19.0–20.6	East	6–12	10/31/83	6.20	5.01	4.46	3.08	4.69
I–64	20.6–22.3	East	30–36	11/01/83	2.54	2.32	2.66	2.17	2.42
I–71	57.89–58.89	South	3–6	6/82	7.12	4.71	2.83	2.20	4.22
I–71			18–24	6/82	2.52	2.73	2.42	2.47	2.54
I–71	58.89–59.89	South	30–36	6/82	1.54	1.41	1.21	1.05	1.30
I–71	56.67–57.91	South	[a]	9/13/83	1.16	0.84	0.74	0.71	0.86
I–71	58.00–58.90	South	3–12	9/13/83	1.68	1.27	0.98	1.21	1.29
I–71	60.00–69.40	South	18–24	9/13/83	1.29	1.02	0.84	0.93	1.02
I–71	59.00–59.90	South	30–36	9/13/83	1.32	1.07	0.92	1.00	1.08
I–71	56.67–69.60	North	18–24	9/13/83	1.51	1.10	0.98	1.08	1.17

[a]No breaking.

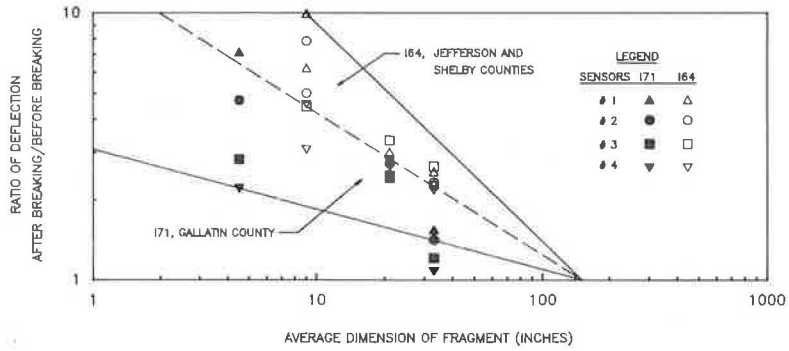

FIGURE 1 Comparison of ratios of deflections for I–64, Jefferson and Shelby counties, and for I–71, Gallatin County.

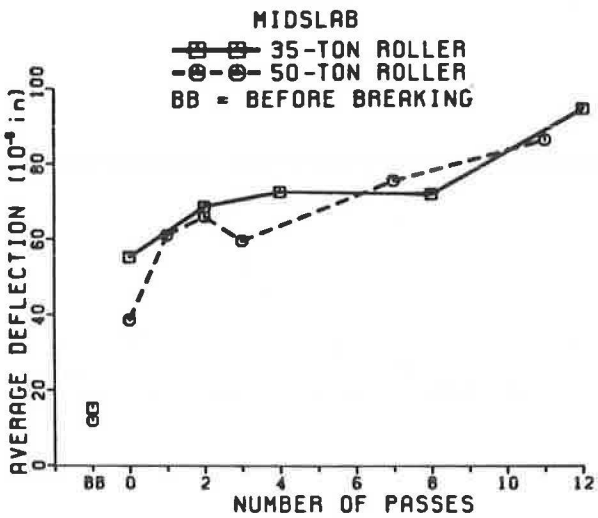

FIGURE 2 Average deflection versus number of roller passes; midslab tests.

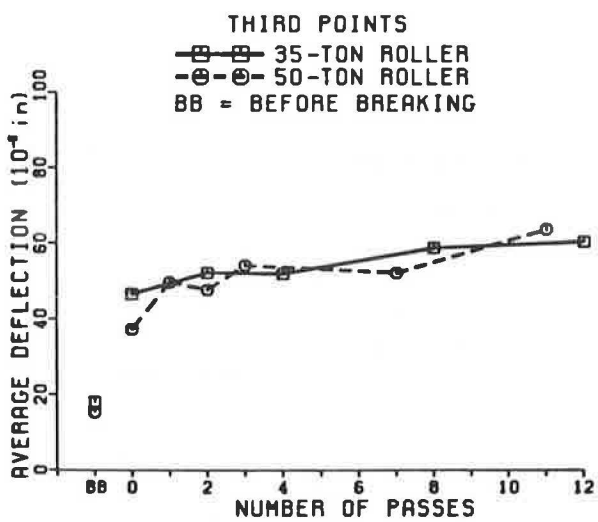

FIGURE 3 Average deflection versus number of roller passes; tests at third points on slab.

may be accelerated by the accumulation of axle loads. A total of 451 lane-miles was surveyed to determine the extent and severity of reflective cracking. The findings of the survey indicate that less than 7.9 lane-miles (one section of pavement)

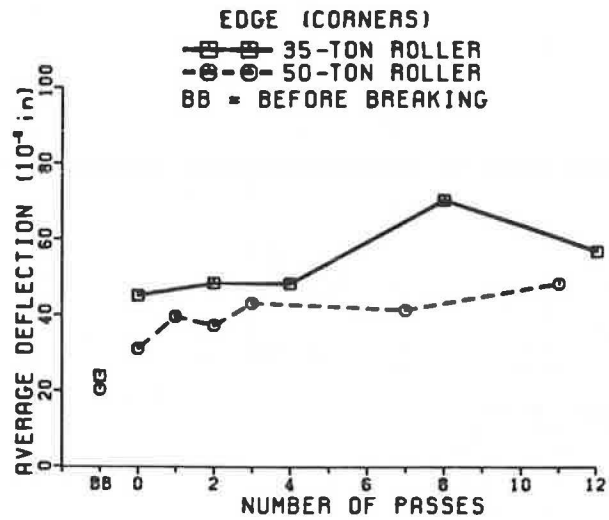

FIGURE 4 Average deflection versus number of roller passes; edge (corner) tests.

were observed to have anything more than an occasional crack. Cracking in this one section was observed within 6 months after placement of the final course of the asphaltic concrete overlay. Measurements indicated very low levels of deflections relative to other sections, suggesting that the existing concrete pavement was not sufficiently broken. Cores from this section failed to show any cracked and broken concrete. Although none of the data cited are conclusive evidence of improper breaking and seating, the accumulation of evidence suggests that the process was not suitably completed in this section. Reflective cracking in less than 2 percent of the surveyed sections with a sampling rate near 50 percent is evidence of the success of this construction process in the short term. It is anticipated that long-term performance will be more likely a function of fatigue.

"Overbreakage" in a few isolated areas has resulted in some localized pavement failures.

Structural Evaluations

Selected pavement sections have been evaluated by deflection testing at various stages of the construction process. Average deflections for a number of sections for two experimental break-and-seat projects are summarized in Tables 1

and 2. Generally, the data may be grouped into the following categories:

- Before cracking: all sections
- After breaking and seating:
  –3- to 12-in. sized fragments
  –18- to 24-in. sized fragments
  –30- to 36-in. sized fragments
- After overlaying:
  –3- to 12-in. sized fragments
  –18- to 24-in. sized fragments
  –30- to 36-in. sized fragments

Data may be evaluated from two perspectives: (a) comparisons of deflections for one section with those of another section and (b) matching of measured deflection basins with theoretically simulated deflections to estimate effective layer moduli.

Ratios of deflections for one stage of construction to another may be used to evaluate the efficiency of breaking. Data from Tables 1 and 2 were used to determine such ratios of deflection. These data are summarized in Table 3 and Figure 1.

There are considerable differences in breaking characteristics from project to project. For example, average ratios of deflections after breaking to those before breaking are summarized as follows:

- I-71, Gallatin County
  –3- to 12-in. fragments: 1.29
  –18- to 24-in. fragments: 1.02 to 2.53
  –30- to 36-in. fragments: 1.03 to 1.08
- I-64, Jefferson and Shelby counties
  –6- to 12-in. fragments: 4.69 to 7.23
  –18- to 24-in. fragments: 2.68 to 2.98
  –30- to 36-in. fragments: 2.41

A more detailed summary of these data is given in Table 3 and Figure 5. Ratios of deflections for after breaking, seating, and overlaying to those before breaking also may be computed. However, these ratios may be more difficult to interpret because of the significant impact of temperature on the relative elastic stiffness modulus of asphaltic concrete. Such ratios provide meaningful comparisons only when data for all tests are standardized to some reference temperature for the asphaltic concrete overlay. Such analyses are not presented in this paper.

Deflection measurements were used to estimate the effective stiffness moduli for the various layers of the pavement structure by means of back-calculation procedures (*8*). There are numerous approaches that may be used, but generally all are iterative and trial-and-error methods. Back calculations become more complex as additional layers are added to the system. The four-layer system, consisting of asphaltic concrete, broken and seated portland cement concrete, crushed stone, and a semi-infinite layer of compacted subgrade, is not yet subject to routine back calculation of effective layer moduli or effective layer conditions for the Kentucky Model 400 or Model 200 Road Raters. Efforts are currently under way, however, to develop and refine such procedures. Analyses presented herein will describe only those trial-and-error approaches to back calculation of effective layer moduli. Information presented in Tables 1 and 2 illustrates average

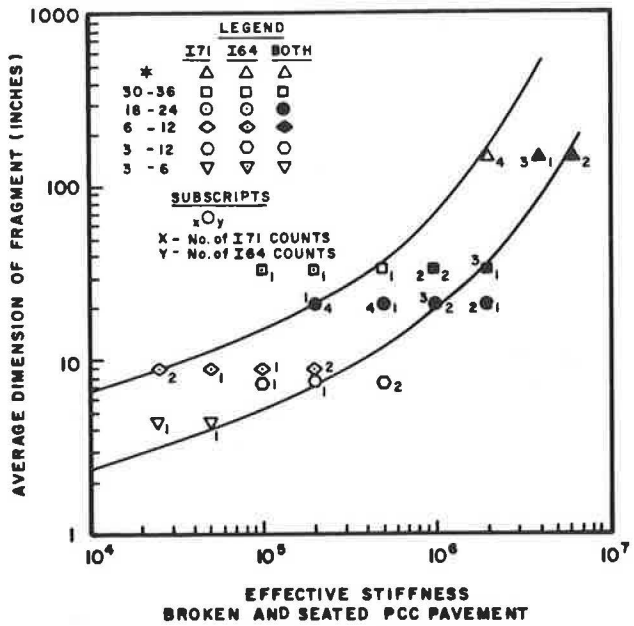

FIGURE 5 Average dimension of fragments versus effective stiffness moduli for cracked and seated portland cement concrete pavements; preliminary design criteria.

deflections for several sections of broken and seated pavements from across Kentucky. Also presented in these tables are simulated deflection basins that approximately match the average deflection basins. These theoretical deflection basins were determined on a trial-and-error basis and do not represent results of a routine procedure for the direct back calculation of effective elastic layer moduli. These analyses do illustrate, however, some significant trends, as follows:

1. There does not appear to be a unique solution for estimation of effective layer stiffness moduli (i.e., more than one combination of layer moduli and layer thicknesses will result in deflection basins closely approximating the measured deflection basin).
2. Effective moduli may be used to "bracket" effective stiffness moduli for the broken and seated concrete pavement. These ranges may be used to estimate appropriate design moduli, as illustrated in Figure 5.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Information presented herein documents the observed performance of rigid pavements that have been recycled in place in Kentucky by breaking and seating followed by an asphaltic concrete overlay. Performance is summarized on the basis of observable or visual conditions as well as deflection testing.

A total of 451 lane-miles of pavement were visually surveyed to determine the extent and severity of reflective cracking. Extensive reflective cracking was observed for only one section involving less than 8 lane-miles, a "failure" rate of less than 2 percent. It was conjectured on the basis of field observations, deflection measurements, and inspection of cores that the observed reflective cracking may have resulted from improper or inadequate breaking or seating, or both.

Some cracking was observed in control sections and transition zones where the existing portland cement concrete pavement was not broken and overlay thicknesses were thinning in transition areas. Reflective cracking in those areas was expected.

Deflection measurements were obtained before, during, and after breaking and seating, and after placement of the asphaltic concrete overlay. Empirical analyses of these deflections were used to evaluate the effectiveness of breaking and seating and of the overlay with asphaltic concrete. These evaluations involved ratios of deflections after breaking to those before breaking, after overlaying to after breaking, and after paving to before breaking. It has been concluded so far that ratios of deflections for before, during, and after breaking and seating activities may provide meaningful insights relative to the extent and effectiveness of the breaking, seating, and overlaying procedures.

It is recommended that construction specifications include a maximum fragment size observable without the aid of a wetted pavement surface. For such specifications to be more effective, further efforts are needed to develop correlations of maximum observable fragment size for an unwetted slab relative to the maximum fragment size observable for the same slab broken to an acceptable breaking pattern and viewed with the aid of a wetted surface. Such observations should be verified by deflection testing. Additionally, specifications should include acceptable ranges of deflection ratios of after breaking (but before overlaying) to before breaking.

Rolling is necessary to stabilize the broken pavement. Rollers as small as 35 tons may be permitted. The minimum number of passes for each roller should be specified. Tentatively, three passes of a 50-ton roller and five passes of a 35-ton roller with a staggered (overlapping) pattern over a 12-ft width appear to be appropriate. These recommendations are based on results of deflection measurements. Three passes of the 50-ton roller will not result in an equivalent level of deflection as will five passes of a 35-ton roller. However, five passes of the 35-ton roller with a staggered pattern should result in more consistent deflection measurements across the slab. This may be attributed to the greater maneuverability of the smaller roller and potential to provide more uniform coverage of the slab.

The principal objective of this paper is to summarize Kentucky experience relating to in-place recycling of rigid pavements. Analyses and evaluations are continuing. Existing data bases are still small and limited. It is essential to continue building and maintaining long-term performance data. Proposed specification criteria must be verified. Efforts to determine the optimum cracking size should continue. Development of a model for the structural behavior of a broken and seated concrete pavement overlaid with asphaltic concrete is necessary for development of a rational thickness design procedure. Procedures for evaluation and back calculation of the effective behavior of such pavements are needed.

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