Research Report
UKTRP-87-26

BREAKING AND SEATING OF RIGID PAVEMENTS

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in cooperation with
Kentucky Transportation Cabinet

and

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FRANKFORT, KENTUCKY 40622

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GOVERNOR

March 7, 1989

Mr. Robert E. Johnson
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, Kentucky 40602-0536

SUBJECT: IMPLEMENTATION STATEMENT
KYHPR-85-108-6, "Breaking and Seating"
UKTRB-87-26, "Breaking and Seating of Rigid Pavements"

Dear Mr. Johnson:

Information gained during the course of work reported in the subject document was used in preparation of the Department's current Special Provision No. 77B, Breaking and Seating Existing Concrete Pavement. Breaking and seating requirements were identified during the study. Projects studied under KYHPR-85-108-6 will be monitored under KYHPR-85-107-4, Cracking and Reflective Cracking -- Breaking and Seating for collection of long-term performance data.

Sincerely,

O. G. Newman, P. E.
State Highway Engineer

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16. Abstract

Breaking and seating has been utilized extensively in Kentucky to rehabilitate portland cement concrete pavements. Experience over three or four years with this type of design and construction are summarized and reported. Breaking to a range of nominal fragments is evaluated. Evaluation of two roller weights for seating is reported. The use of dynamic deflections to evaluate the effectiveness of the breaking and seating process and to measure the appropriateness of the asphaltic concrete overlay.

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EXECUTIVE SUMMARY

Two basic techniques for rehabilitating rigid pavements include recycling and over laying. Recycling may be done at a central plant or in place. In-place recycling consists of converting the existing concrete pavement to a base and then overlaying with either asphaltic concrete or portland cement concrete. Breaking and seating the existing concrete followed by placement of a relatively thick asphaltic concrete overlay has been used extensively in Kentucky since 1982 for rehabilitation of existing rigid pavements.

Breaking patterns for pavement sections have varied from 3-to 12-inch fragments, to 18-to 24-inch fragments, to 30- to 36-inch and larger fragments. The majority of pavements have been specified for cracking to an 18-inch nominal breaking pattern.

Breaking equipment varies. Two devices used in Kentucky include a whiphammer and a modified pile-driving hammer. The modified pile- driving hammer has been used more extensively and has been subject to less controversy than the whiphammer. The whiphammer is controversial because of suspected "under breakage" for some sections. The modified pile-driving hammer also has been controversial because punching failures or column-like pavement fragments have been observed.

Pavement seating procedures also have varied. Generally, rollers used for pavement seating have been 35- or 50-ton rollers. Thirty-five ton rollers have generally been of the multi-wheel pneumatic tire variety whereas the 50-ton rollers have been two-wheel (trailer type) devices having rubber tires. Asphaltic concrete overlay thicknesses have varied from about 4 to 5 inches (for non-interstate high-type (parkway, primary routes) pavements) to 7 inches on the interstate projects. A specific thickness design procedure for determination of overlay thicknesses (asphaltic concrete) for a broken concrete "base" does not yet exist. Currently, designs are determined

assuming the fractured concrete will behave no worse than conventional dense-graded limestone base material.

Evaluations have involved visual observations of performance after construction and deflection testing before, during, and after construction. Deflection measurements have been used to compare the seating effectiveness of a 35-ton roller and a 50-ton roller.

Performance generally has been outstanding. Of more than 1,031 lane miles where these techniques have been used, serious and extensive reflective cracking has been observed in only one section. That section was on I 71 in Henry County in the southbound lanes on the project between MP (mile point) 24.80 and MP 30.05. Most distress was between MP 34.9 and MP 31.1 with 2.1 miles of extensive distrees in the right lane and 0.88 mile in the left lane. That cracking was attributed to inadequate breaking and/or seating. There have been some isolated locations where "overbreakage" resulted in spot pavement failures were observed. Cracking has been observed in transition zones and control sections where the existing portland cement concrete pavement was not broken and/or overlays were decreasing in thickness. Cracking in those areas was expected.

Deflection measurements before, during, and after breaking and seating and after placement of the asphaltic concrete overlay have been analyzed. Use of elastic theory to model deflection behavior of broken portland cement concrete indicated that, generally, an effective elastic modulus of 9 to 30 ksi may be associated with concrete fractured to 3 to 6 inches; an effective elastic modulus of 50 to 1,000 ksi may be associated with fragments of 18 to 24 inches, and an effective elastic modulus of 600 to 2,000 ksi may be associated with 30- to 36-inch fragments.

Empirical analyses have been used more frequently to evaluate the effectiveness of breaking and seating and of the overlay. These evaluations have involved ratios of deflections after breaking, and after paving to before breaking. Experience to date indicates a ratio of deflections after breaking to before breaking on the order of 4 for fragments judged to be 3 to 12 inches. Ratios of 2.5 to 3 have been associated with fragments of 18 to 24 inches. Ratios of 2 have been associated with fragments greater than 30 inches. Ratios of deflections for after paving are still being evaluated but may be expected to vary depending upon overlay thickness. All ratios may be expected to vary depending upon subgrade conditions. Ratios of deflections may provide meaningful insights relative to the extent and/or effectiveness of breaking, seating, and overlaying.

Specifications have been modified to include a maximum fragment size observable without the aid of a wetted pavement surface. Additionally, it is recommended that specifications ultimately include acceptable ranges of deflection ratios for after breaking/before breaking. Deflections should be measured at the discretion of the project engineer to assist evaluation of the observed breaking pattern.

Current specifications in Kentucky require either a 35-ton or a 50-ton pneumatic-tired roller for seating broken concrete pavement. Early research has indicated, tentatively, that five passes of the 50-ton roller and seven passes of the 35-ton roller with a staggered (overlapping) pattern will provide the necessary seating. Five passes of the 50-ton roller will not necessarily result in an equivalent level of deflections as seven passes of a 35-ton roller. However, seven passes of the 35-ton roller with a staggered rolling pattern may result in more consistent deflection measurements across the slab. This may be attributed to the greater number of tires contacting the pavement surface for the 35-ton roller when compared with the 50-ton roller.

The principal objective of this report 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 assembling and maintaining long- term performance data. Proposed specifications should be verified. Efforts to determine the optimum fragment size should continue. Development of a model for the structural behavior of a broken and seated port land cement 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 currently being studied.

RECYCLING OF RIGID PAVEMENTS

Rigid (portland cement concrete) pavements are deteriorating rapidly in many areas of the country. Spalling, cracking, joint deterioration, and faulting at joints and/or 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 for rehabilitating rigid pavements include recycling and overlaying. Recycling may be done at a central plant or in-place. Centralized recycling typically involves pulverization of the existing concrete pavement, removal of the fragmented material, processing the material (crushing, grading, removal of steel, stock piling), and use of 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 with either asphaltic concrete or portland cement concrete.

Reflection cracking of existing cracks and/or joints of the underlying pavement is a major problem when asphaltic concrete overlays are used over unbroken rigid pavements. Techniques employed specifically to reduce and/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 inches) asphaltic concrete overlay and b) placement of a crack-relief layer followed by a moderately thick overlay (less than 4 inches) of asphaltic concrete.

A typical crack-relief layer consists of 3 to 4 inches of open- graded bituminous material placed over an existing rigid pavement. Another 3 to 4 inches 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 by 3 feet to 4 by 6 feet and overlay thicknesses used nationally range from 2 3/4 inches to 7 3/4 inches. Prices for breaking and seating have varied from $0.25 per square yard to $2.00 or more per square yard (1, 2, 3).

Types of breaking devices include a pile driver with a modified shoe, a transverse drop-bar (guillotine) hammer, a whiphammer, an impact hammer, and a resonant pavement breaker. There also are many different methods of seating broken concrete particles. Roller sizes have varied from 44,000 to 100,000 pounds (1). Pneumatic-tired rollers weighing 35 to 50 tons are the more common, 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 1988, over 1,031 lane miles of pavement have been broken, seated, and over-laid with asphaltic concrete. Performance has been generally outstanding; 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 (copies available upon request) 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 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. There is a need to determine the validity of this assumption.

BREAKING PATTERNS

The condition of the existing rigid pavement may significantly influence the manner in which a pavement will fracture. The resultant breaking pattern apparently is a function of the energy absorbed by the slab and the manner in which the energy is dissipated throughout the slab and pavement structure. Dissipation of energy is dependent upon the strength and/or thickness of the existing concrete, joint and/or crack spacing and condition, and degree of deterioration of the slab. Other factors may include temperature and time of day, affecting 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 temperatures. 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 upon design considerations as well as the long-term performance of the overlay. Small fragments will most certainly reduce and possibly eliminate reflective cracking in the asphaltic concrete overlay but utilize 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 so large as to permit thermal movements of the existing pieces and thereby maintain the potential for reflective cracking. The existence of severe D cracking might appreciably affect performance of larger fragmented sections. Large fragments also may have more potential for rocking as a result of ineffective seating and therefore increase the potential for cracking of the overlay. Research in Kentucky has involved three ranges of nominal fragment sizes for cracked concrete: a) 3 to 12 inches, b) 18 to 24 inches, and c) 30 to 36 inches. Current Kentucky specifications (4) require pavements to be broken to a nominal 24-inch size and permit up to 20 percent of the fragments to exceed 24 inches. Pieces larger than 30 inches are not permitted. Research is continuing to determine the optimum size for fragmenting portland cement concrete pavements. At this time, there appears to be no definite conclusions.

Current specifications require viewing fragmentation patterns of a dry surface (4). Also, there is 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 breaking 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 the subjectivity. Visual evaluations 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 specifications allowed the cracking pattern to be viewed by wetting the pavement surface. Wetting the surface presented inspection problems since numerous hairline surface cracks were observed but could not be distinguished from full depth crachs. Some cracking may be observed without the aid of a wetted surface and is dependent upon 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. Watering the surface was discontinued because wetting exposed cracks which were present prior to breaking and seating.

Deflection testing provides a more objective and definitive comparison of before-and-after conditions. The principal problem associated with deflection testing for acceptance and/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 data. In addition, desired deflections upon completion of breaking and seating have not been established.

BREAKING EQUIPMENT

Three types of pavement breakers have been used in Kentucky: a) pile-driving hammer, b) transverse-bar drop hammer (guillotine), and c) whiphammer. The pile-driving hammer and the whiphammer 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 altered 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-inch fragments may be achieved when the pile- driving hammer traverses a slab with three or four passes per 12-foot lane width equally spaced transversely across the slab and the interval between impact blows of the hammer is 12 to 18 inches. The required transverse spacing of passes, interval between impact blows, number of passes, and hammer throttle setting would be 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 fragment sizes of 30 to 36 inches may be achieved with two or three passes of a pile hammer at an interval of 12 to 18 inches between impact blows. Similarly, fragments of 3 to 12 inches may result from seven to eight passes and the same 12- to 18-inch 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 impacts the pavement. Breakers used in Kentucky typically have a plate-type "shoe" to prevent or minimize penetration or punching into the surface of the existing portland cement concrete pavement. Apparently, the most effective "shoe" is a square (on the order of 18 inches 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 whiphammer consists of an impact hammer attached to the end of a leaf-spring arm. The whiphammer may be moved in the horizontal as well as the vertical directions. 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 with the pile-driving hammer. Typically, the plate will have a diamond, square, or rectangular shape. The whiphammer 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 whiphammer is apparently a function of the pressure in the hydraulic system and the resiliency and number of leaf springs supporting the hammer head. As 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 whiphammer typically are applied in a more random fashion than 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 whiphammer may be maneuvered in an arc, typically providing a coverage of approximately an 8-foot arc. An 18- to 24-inch breaking pattern usually may be achieved with one blow of the whiphammer per square foot of pavement surface area. The whiphammer has not yet been used in Kentucky to break rigid pavement to other sizes. As 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 inches. The operator varies the speed of travel and thereby controls the interval between impacts. The force of impact may pbe varied by changing the height of the drop (1, 2).

SEATING

Seating the fragments is necessary to assure a stable foundation for the asphaltic concrete overlay. With inadequate seating, individual fragments tend to rock, increasing the potential for reflection cracking. As 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 thereby eliminating voids in the pavement structure. Experience thus far has indicated 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. A 30-ton pneumatic-tired roller on the first project. The roller was not adequate because the pavement had not been broken as specified. Subsequent projects required seating by a 50-ton pneumatic-tired roller. Recent evaluations, however, have indicated the 35-ton pneumatic-tired roller to be nearly as effective although requiring more passes. Currently, a 35-ton pneumatic-tired roller is the smallest roller permitted.

EVALUATIONS

EFFECTIVENESS OF BREAKING

A simplified technique for evaluating deflections obtained before, during, and after breaking portland cement concrete pavement as well as after paving has been used. Deflections of two pavements are presented in Tables 1 and 2 as an example. The tables present average field measured def lections 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 between fragment size, effective stiffness modulus, and ratio of deflections (after breaking/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 Seton roller for a subsequent project. Results of the latter evaluation are summarized by Figures 2, 3, and 4. Data from three locations (midslab, opposing third points, and opposing edges (corners)) are presented. 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 the 50-ton roller. This is not surprising, since 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 insure seating at the edges.

In California (1, 2), a vibratory sheepsfoot roller weighing 44,000 pounds was used. Ten rolling passes were applied in each half of a 12-foot lane. The roller width of 8 feet resulted in overlapping of the middle 4 feet 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 by Figures 2, 3, and 4. It has been conjectured that the initial reduction and/or 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 with regard to 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.

Practicality tends to dictate usage 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 mapeuverable 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, 6, 7) and results of deflection measurements, it is recommended that the minimum size roller for seating be 35 tons. Multi-tired pneumatic rollers are recommended in lieu 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 assure 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 magnitude of deflection after rolling.

SHORT-TERM PERFORMANCE

The oldest in-service section of broken and seated portland cement concrete over laid with asphaltic concrete was completed in October 1983. It is suspicioned that none of the pavement sections has been subjected to an accumulation of fatigue (18-kip equivalent axleloads (EALs)) necessary for the manifestation of visual surface distresses. Fatigue accumulation for manifestation of distresses has not been determined.

Reflection cracking of the asphaltic concrete overlay, while not specifically associated with structural deterioration, may be accelerated by the accumulation of axleloads. A total of 451 lane miles was surveyed to determine the extent and severity of reflective cracking. The findings of the survey indicate that one section of pavement was 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 above data is conclusive evidence of improper breaking and/or seating, the accumulation of evidence suggests that the process was not suitably completed in this section. Reflective cracking in less than two 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 a function of fatigue.

A few isolated and localized overlay failures were observed. Two failures were the result of water within the base. Causes of other failures were not identified.

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:

A. Before Cracking: all sections

B. After Breaking and Seating:
    3- to 12-inch size fragments
    18- to 24-inch size fragments
    30- to 36-inch size fragments

C. After Overlaying

3- to 12-inch size fragments
18- to 24-inch size fragments
30- to 36-inch size fragments

Data may be evaluated from two perspectives: 1) comparisons of deflections for one section to those of another section and 2) matching of measured deflection basins with theoretically simulated deflections for the purpose of estimating 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 below:

I 71, Gallatin County

3- to 12-inch fragments:	1.29
18- to 24-inch fragments:	1.02 to 2.53
30- to 36-inch fragments:	1.03 to 1.08

I 64, Jefferson and Shelby Counties

6- to 12-inch fragments:	4.69 to 7.23
18- to 24-inch fragments:	2.68 to 2.98
30- to 36-inch fragments:	2.41

A more detailed summary of these data is given in Table 3 and Figure S. 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. Back calculations become more and 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, however, are currently underway 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 deflections for several sections of broken and seated pavements from across Kentucky. Tables 1 and 2 also present 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:

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, 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 two 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 and/or seating. Some cracking was observed in control sections and transition zones where the existing portland cement concrete pavement was not broken and/or overlay thicknesses decreased in transition areas. Reflective cracking in those areas was expected.

Deflection measurements were obtained before, during, after breaking and seating, and after placement of the asphaltic concrete overlay. Empirical analyses of those 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 over laying to after breaking, and after paving to before breaking. It has thus far been concluded that ratios of deflections for before, during, and after breaking and seating activities may provide meaningful insights relative to the extent and/or 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 or simply the end product. Such observations could be verified by deflection testing during trial periods. Additionally, specifications should include acceptable ranges of deflection ratios of after breaking (but before over laying) 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-foot width appear to be appropriate. These recommendations are based upon results of deflection measurements. Three passes of the SO-ton roller will not result in an equivalent level of deflection as 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 was 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 over laid 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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2. "Cracking and Seating of PCC Pavements Prior to Overlaying with Hot Mix Asphalt: State of the Art," National Asphalt Pavement Association, Information Series 98, 1987.

3. "Cracking and Seating, Remedy or Rhetoric?" Hale, T. C., Field Editor, ConstYutti6H Digest, April 4, 1985.

4. "Special Provision No. 77A (85), Breaking and Seating of Existing Concrete Pavement," Department of Highways, Kentucky Transportation Cabinet, February 1987.

5. "Asphalt Overlays on Cracked and Seated Concrete Pavements," Eckrose, R. A., and Poston, W. E., Donohue and Associates, Inc., Elkhorn, Wisconsin, April 1982.

6. "Structural Evaluation of Crack and Seat Overlay Pavements," Lukanen, E. O., Midwest Pavement Management, Inc., September 1986.

7. "Crack and Seat Performance," Review Report, Federal Highway Administration, Demonstration Projects Division and Pavements Division, April 1987.

8. "Nondestructive Evaluation of Rigid Pavements Using Road Rater Deflections," G. W. Sharpe, M. Anderson, R. C. Deen, and H. F. Southgate, Pro˜e˜dings, Third International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, April 23-25, 1985.

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

										THEORETICAL DEFLECTIONS									
										STIFFNESS MODULI (KSI)						THEORETICAL DEFLECTIONS (INCHES X 10^{-5})			
				TERMINI		FIELD DEFLECTIONS[a] (INCHES X 10^{-5})				ASPHALTIC CONCRETE									
PARTICLE SIZE (INCHES)	TEST DATE	SURFACE TEMP. °F	DIRECTION	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 4008 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 2. SUMMARY OF ANALYSES OF DEFLECTION MEASUREMENTS: I 71, GALLATIN COUNTY

										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
*	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	10.5	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 / BEFORE BREAKING

					RATIOS				
					SENSORS				
ROUTE	TERMINI	DIREC-TION	PARTICLE SIZE	DATE	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	*	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

* NO BREAKING

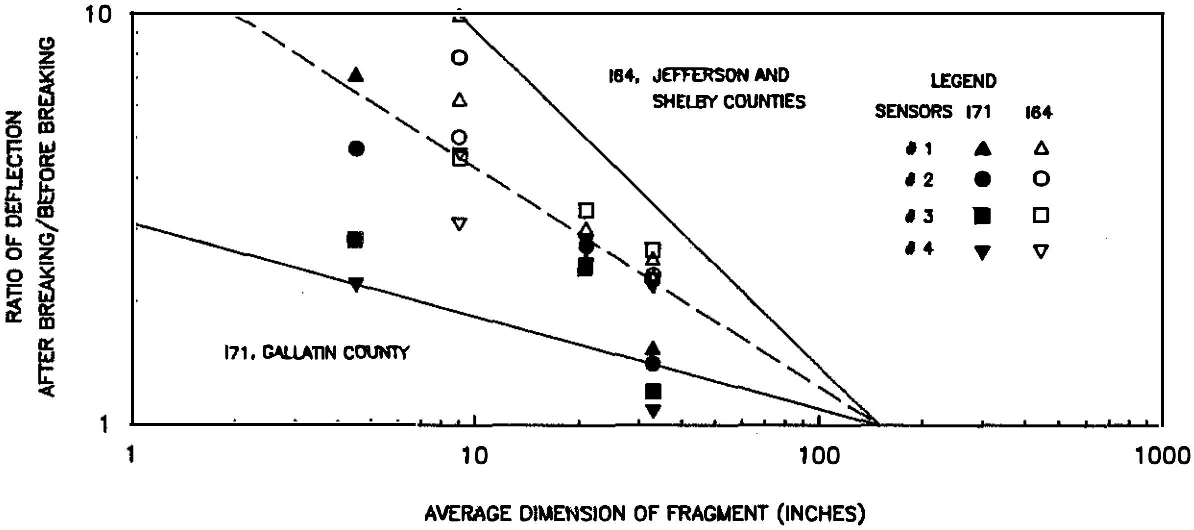

Figure 1. Comparison of Ratios of Deflections for I 64, Jefferson and Shelby Counties, and for I 71, Gallatin County.

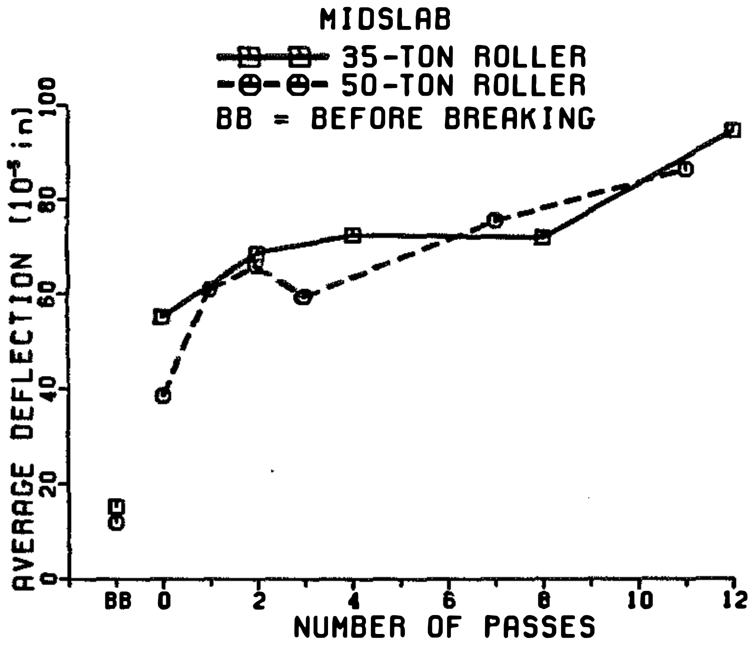

Figure 2. Average Deflection versus Number of Roller Passes; Midslab Tests.

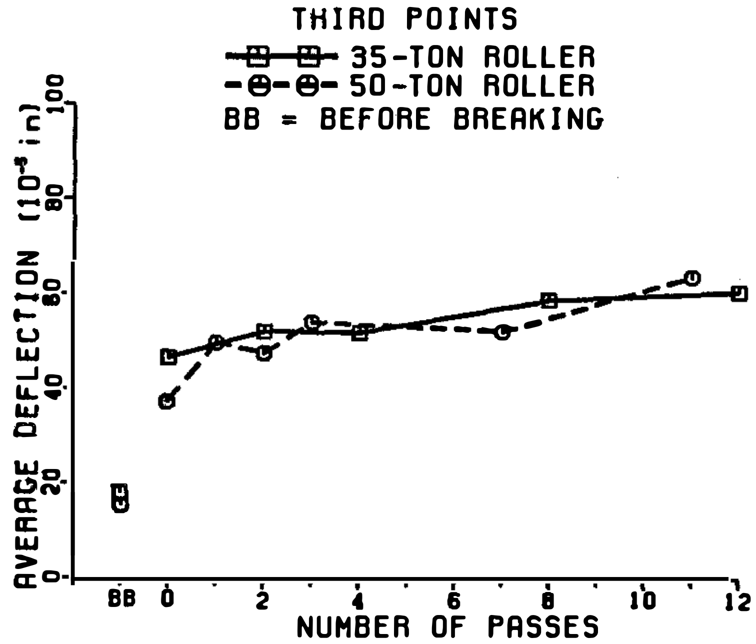

Figure 3. Average Deflection versus Number of Roller Passes; Tests at Third Points on Slab.

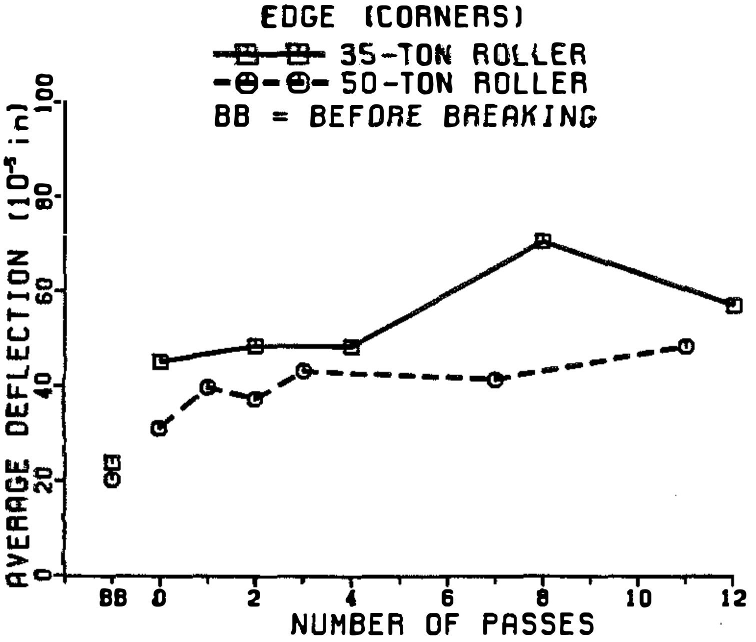

Figure 4. Average Deflection versus Number of Roller Passes; Edge (Corner) Tests.

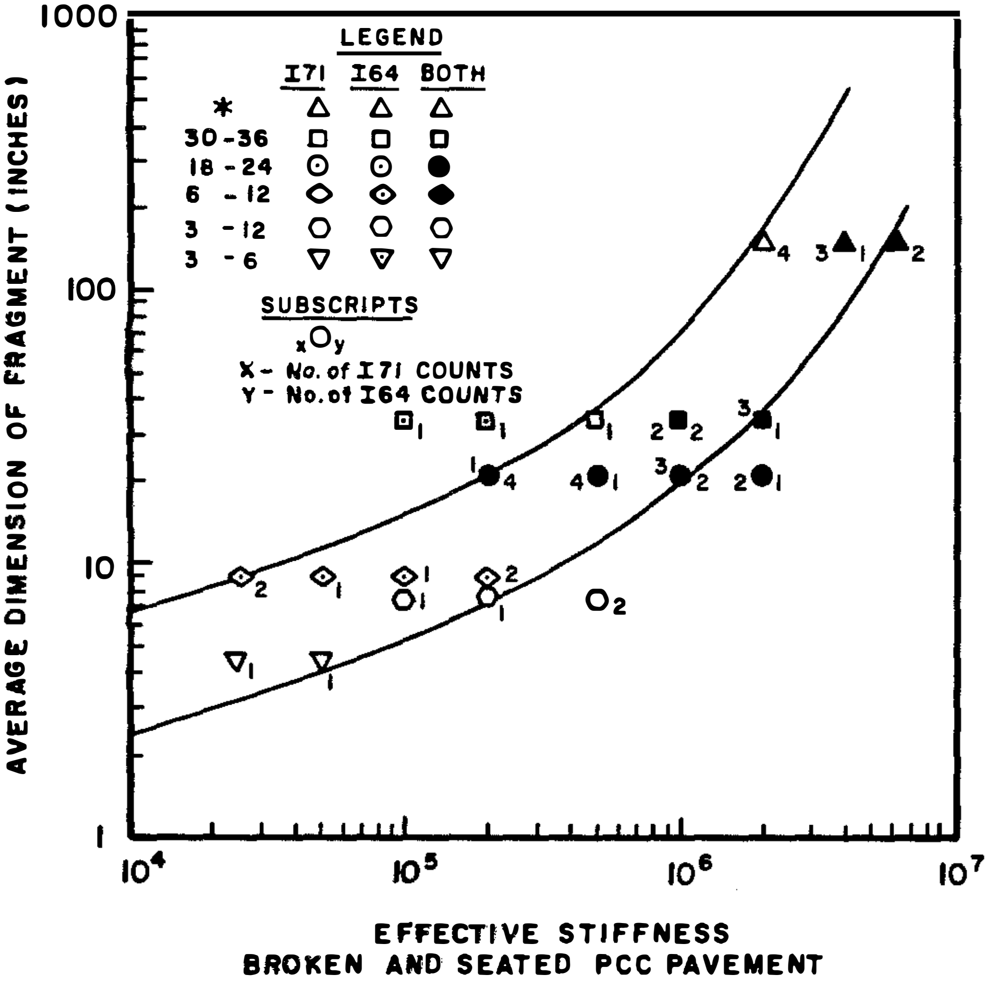

Figure 5. Average Dimension of Fragments versus Effective Stiffness Moduli for Cracked and Seated Portland Cement Concrete Pavements; Preliminary Design Criteria.