VARIABLE SERVICEABILITY CONCEPT FOR PAVEMENT DESIGN CONFIRMED BY AASHO ROAD TEST FATIGUE DATA

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16. Abstract

Fatigue data from the AASHO Road Test were plotted for each level of serviceability. The Kentucky thickness design system uses the concept of a variable level of serviceability as a function of EALs. The Kentucky thickness design curve for the equivalent CBR was converted to an equivalent structural number and superimposed on each of the specific serviceability figures. The AASHTO Equation C-14 of the 1972 AASHTO Interim Guide was evaluated for each level of serviceability and superimposed on its respective figure. Equation C-14 fits reasonably well for serviceability levels of 2.0 and 2.5 but does not fit the remaining serviceability levels. The Kentucky thickness curve is asymptotic to a portion of each figure and directly related to level of serviceability. Figure 6 is a composite of portions of Figures 1 through 5 created by lifting the portion of each level of serviceability for which the Kentucky thickness design curve was asymptotic to the data for a specific range in EAL. The composite figure illustrates the potentiality of the AASHTO design method being expressed by one nomograph (not developed or shown herein) in which the serviceability level increases as EAL increases.

17. Key Words AASHO Road Test, EAL, Structural Number, CBR, Soil Support, Single Axleload, Tandem Axleload, Fatigue, Level of Serviceability	18. Distribution Statement

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INTRODUCTION

The AASHTO Design Method uses equations for a four-tired single axle and eight-tired tandem axle to calculate the design 18-kip EAL's used to determine the Structural Number, SN. At the time those load-equivalencies were developed, the front axle usually carried a light load. For example, single-axle trucks driven on Lane 1 of Loop 4 of the AASHO Road Test had a front axleload of 5.6 kips (1), corresponding to 0.046 EAL. However, in the 1970's, larger and larger front axleloads have become increasingly prominent. A typical front axleload for a "cab-over" style tractor truck in 1983 ranged between 12 to 14 kips. A new "cab-over" tractor has a typical front axleload of 13 kips, which corresponds to 0.72 EAL. Thus, the ratio of increased load is 13.0/5.6 = 2.32, which has a corresponding increase in load equivalency of 0.72/0.046 = 15.65. Therefore, the heavier loads on the steering axles stimulated the development of load-equivalency factors for the steering axle.

LOAD EQUIVALENCIES

In the late 1970's, Kentucky research efforts yielded new load-equivalency relationships for the two-tired and four-tired single axles and eight-tired tandem axles (2). Those relationships are summarized in Table 1. The actual loads for each axle group on the test vehicles at the AASHO Road Test were obtained (1), and load-equivalency factors were calculated for each axle group using relationships from Table 1. The load equivalency for each axle group was summed to obtain the total equivalency for a given vehicle (see Table 2).

FIXED VERSUS VARIABLE SERVICEABILITY

The AASHTO Interim Guide (3) provides nomographs for two levels of terminal serviceability for designing pavement thicknesses using asphaltic concrete. Both levels of serviceability are appropriate for low- to medium-type facilities but are not applicable for high-type facilities such as interstate highways. The Kentucky design method (4, 5) is based upon some 45 years of pavement testing, design, and experience coupled with elastic theory and strain-fatigue criteria, and incorporates levels of serviceability that change according to the design EAL. The logic employed considers that farm-to-market roads should be assigned a lower level of terminal serviceability, permitting more cracking and deeper rut depths because the geometrics of the route would not permit vehicle speeds to reach hydroplaning conditions. At the upper end, interstate pavements should be assigned the highest level of terminal serviceability to minimize pavement defects and reduce the chance of vehicles hydroplaning at operating speeds. The purpose of this analysis was to determine if the AASHO Road Test fatigue data supported the concept of variable levels of serviceability used in the Kentucky design method.

FATIGUE-SERVICEABILITY ANALYSES

The observed number of vehicle trips at the AASHO Road Test (6) had been multiplied by 2 because "two applications of load were made per trip". Those counts were multiplied by load-equivalency factors obtained by using Equation C-14 (3) and then multiplied by weighting factors to adjust for seasonal effects (6). Thus, the number of vehicle trips multiplied by the total load equivalency factor for the vehicle type yields the total fatigue applied to that pavement at a given level of service. Figures 1 through 5 correspond to levels of serviceability of 1.5 through 3.5 by 0.5 increments, respectively, and illustrate the relationship between structural number and adjusted EAL. Structural coefficients of 0.44 for asphaltic concrete, 0.14 for granular base material, and 0.11 for subbase material used in this analysis are the same values as those derived from the AASHO Road Test data and recommended in the 1981 AASHTO Interim Guide (3).

Two curves have been superimposed on Figures 1 through 5. The lower curve is the solution of Equation C-14 (3). Figures 2 and 3 correspond to levels of serviceability of 2.0 and 2.5, respectively, and show that Equation C-14 fits the data in a reasonable manner; but in Figures 1, 4, and 5, the curves have a significant skew to the data. One partial explanation is that load-equivalency factors are represented by a parabolic equation in the Kentucky method and by a log-log straight line equation in the AASHTO method. The skew in Figures 4 and 5 is more related to the form of Equation C-14 than to the parabolic equation for load equivalencies. Thus, Equation C-14 does not adequately describe the relationship between structural number, load, level of serviceability, and repetitions.

The upper curve represents thicknesses corresponding to a Young's modulus of elasticity of 480 ksi and a CBR of 5.2 from the 1981 Kentucky thickness design method. Samples of the subgrade at the AASHO Road Test were evaluated by the Kentucky CBR test method. Results indicated a CBR of 5.2 correlated to a Soil Support value of 3.0 (7). The Kentucky CBR test differs from the ASTM method in the time the sample is subjected to soaking. The sample is allowed to soak until swelling ceases. The remainder of the test is identical to the ASTM standard procedure.

Thicknesses from the 480-ksi Kentucky design curves were converted to structural numbers using the same coefficients described earlier. Over a given year, the modulus varies greatly, but 480 ksi is a mean value that adequately has described behavior over a 35-year period. The literature (8) also reports a single value of 600 ksi for the AASHO Road Test but states that the modulus varied widely according to temperature and time. In the Kentucky method (4, 5), the level of serviceability was not explicitly specified, but was implied to have a low value for a "farm-to-market" road, increasing in minimum serviceability values for increasingly higher-type facilities, and would have a minimum level of serviceability of 3.5 for highways designed to 4 million and greater 18-kip EAL.

The serviceability rating system was developed at the AASHO

Road Test.   A value of 3.5 was assumed to be the point at which
deterioration of some sort would begin. For a given structural
number, the wide scatter in the EAL's can be attributed to a
number of compounding factors such as:

     1.   Personnel were gaining experience using the new system
to rate the various pavement sections.   In some of the thinner
pavement sections, a value of 3.5 was reached shortly after the
first spring thaw.
     2.   A value of 3.5 corresponds to a pavement condition for
which it would be difficult to detect deterioration in ride
quality and surface appearance.
     3.   The structural number (sum of the products of the layer
thicknesses and their corresponding coefficients) can be
identical for quite different combinations of layer thicknesses.
     4.   The serviceability index is a subjective instrument of
measure.

Table 3 shows that the lowest values for the correlation
coefficients and the F ratios occurred at a serviceability value
of 3.5.   The values increased as the serviceability value
decreased to 2.5 and then decreased (scatter increased) to a
serviceability of 1.5.   At 1.5, the scatter may be attributed to:

     1.   The number of pavement sections to reach this level of
severe deterioration was fewer than at any other level of
serviceability.
     2.   The rate of change in serviceability from 2.0 to 1.5
generally was very rapid (fewer EAL's) than for any other 0.5
decrement of serviceability.
     3.   The change of serviceability from 2.0 to 1.5 may have
occurred between scheduled "rating days".

Despite problems cited above, the agreement was amazingly good,
especially for the lower levels of serviceability.   By the time
the test sections reached those lower levels of serviceability,
crews were well trained in using the rating system and rated the
sections in a critical fashion.
     Inspection of Figures 1 through 5 reveals that, up to 4
million EAL's, the 480-ksi Kentucky design curve incorporates two
standard deviations within a particular range of 18-kip EAL's for
a specific level of serviceability as shown in Table 4.   The
equation that seemed to best fit the mean of the data took a
parabolic form with a standard error of estimate of 0.0469 and
correlation coefficient of 0.894.   For EAL's greater than 4
million, the 480-ksi curve requires a thickness greater than the
mean plus two standard deviations.   The Kentucky criteria for
vertical compressive strain vs EAL has a downward hook that
causes the greater thickness requirement, but some designers
would look upon this as just providing a greater factor of safety.
     Figures 1 through 5 and Tables 3 and 4 indicate that a
composite of the five sets of data would provide a variable level
of serviceability as a function of EAL.   Figure 6 is a composite
of portions of Figures 1 through 5 created by lifting out the
portion of each level of serviceability for which the Kentucky

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thickness design curve was asymptotic to the data for a specific range in EAL using the ranges of EAL listed in Table 4. Note that the 480-ksi Kentucky curve incorporates 90 percent of the AASHO Road Test data and without a skew to the data. The 480-ksi curve also illustrates that the recorded EAL's at the AASHO Road Test match results of analyses using elastic theory. Figure 6 suggests that the AASHTO design nomographs could be replaced with one nomograph that incorporates a variable level of serviceability as a function of EAL and also could include levels of confidence based upon statistics.

SUMMARY

Fatigue data from the AASHO Road Test were plotted for each level of serviceability. The Kentucky thickness design system uses the concept of a variable level of serviceability as a function of EAL's. The Kentucky thickness design curve for the equivalent CBR was converted to an equivalent structural number and superimposed on each of the specific serviceability figures. The AASHTO Equation C-14 of the 1972 AASHTO Interim Guide was evaluated for each level of serviceability and superimposed on its respective figure. Equation C-14 fits reasonably well for serviceability levels of 2.0 and 2.5 but does not fit the remaining serviceability levels. The Kentucky thickness curve is asymptotic to a portion of each figure and directly related to level of serviceability. Figure 6 is a composite of portions of Figures 1 through 5 created by lifting the portion of each level of serviceability for which the Kentucky thickness design curve was asymptotic to the data for a specific range in EAL. The composite figure illustrates the potentiality of the AASHTO Design Method being expressed by one nomograph (not developed or shown herein) in which the serviceability level increases as EAL increases.

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TABLE 1. REGRESSION COEFFICIENTS TO CALCULATE DAMAGE
          FACTORS FOR VARIOUS AXLE CONFIGURATIONS
===

$LOG(DAMAGE\ FACTOR) = A + B(LOG\ (LOAD)) + C[LOG\ (LOAD)]^2$

| | COEFFICIENTS | | |
AXLE CONFIGURATION	A	B	C
Two-tired Single Front Axle	-3.540112	2.728860	0.289133
Four-Tired Single Rear Axle	-3.439501	0.423747	1.846657
Eight-Tired Tandem Axle	-2.979479	-1.265144	2.007989
Twelve-Tired Tridem Axle	-2.740987	-1.973428	1.964442

TABLE 2. LOAD EQUIVALENCY FACTORS FOR VEHICLES
          AT AASHO ROAD TEST
===

LOOP NUMBER	AXLE GROUP	DAMAGE FACTOR PER VEHICLE TRIP
3	SINGLE	0.330
	TANDEM	0.319
4	SINGLE	2.173
	TANDEM	1.173
5	SINGLE	6.837
	TANDEM	3.043
6	SINGLE	33.564
	TANDEM	8.30

TABLE 3. REGRESSION COEFFICIENTS AND STATISTICAL ANALYSES
          FOR EQUATIONS OF BEST FIT IN FIGURES 1 THROUGH 5

===

$LOG(SN) = a + b(LOG (EAL)) + c[LOG (EAL)]^2$

IN WHICH SN = AASHTO STRUCTURAL NUMBER

| LEVEL OF SERVICEABILITY | COEFFICIENT | | | ESTIMATE OF ERROR | CORRELATION COEFFICIENT | F RATIO |
	a	b	c			
1.5	-1.10766	0.46704	-0.03114	0.04914	0.8703	637.5
2.0	-1.04632	0.44402	-0.02884	0.04794	0.8781	731.4
2.5	-0.89202	0.38977	-0.02382	0.04491	0.8953	914.7
3.0	-0.93799	0.39662	-0.02358	0.04993	0.8746	774.5
3.5	-0.68836	0.32941	-0.01844	0.08505	0.6967	259.5
VARIABLE	-0.98009	0.40908	-0.02434	0.04691	0.0894	906.7

TABLE 4. RELATIONSHIP BETWEEN EAL AND
          SERVICEABILITY USED IN FIGURE 6

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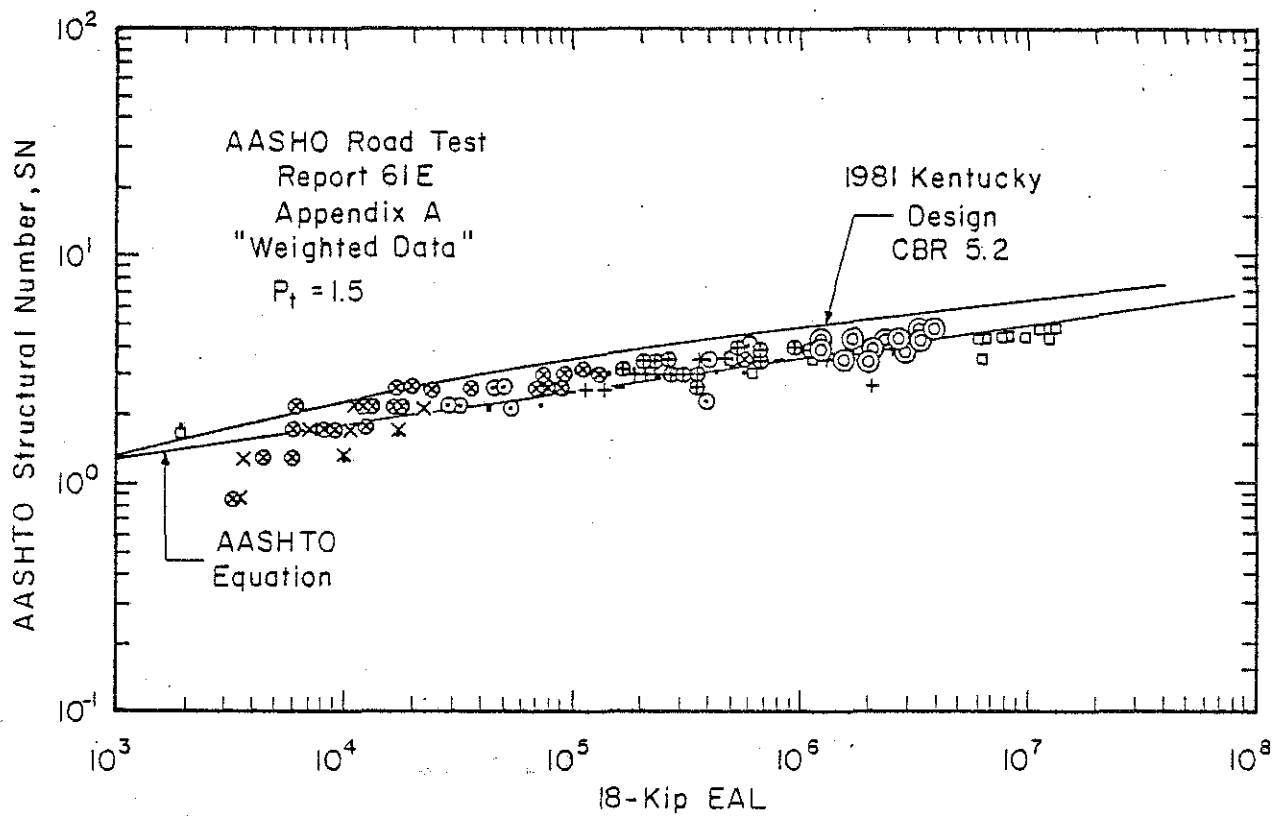| LEVEL OF SERVICEABILITY | 18-KIP EAL's, MILLIONS | |
	FROM	TO
1.5	0.0	0.003
2.0	0.003	0.03
2.5	0.03	0.3
3.0	0.3	3.0
3.5	>3.0	

FIGURE 1. COMPARISON OF KENTUCKY DESIGN CURVE, SOLUTION OF AASHTO
EQUATION C-14, AND REPETITIONS AT THE AASHO ROAD TEST
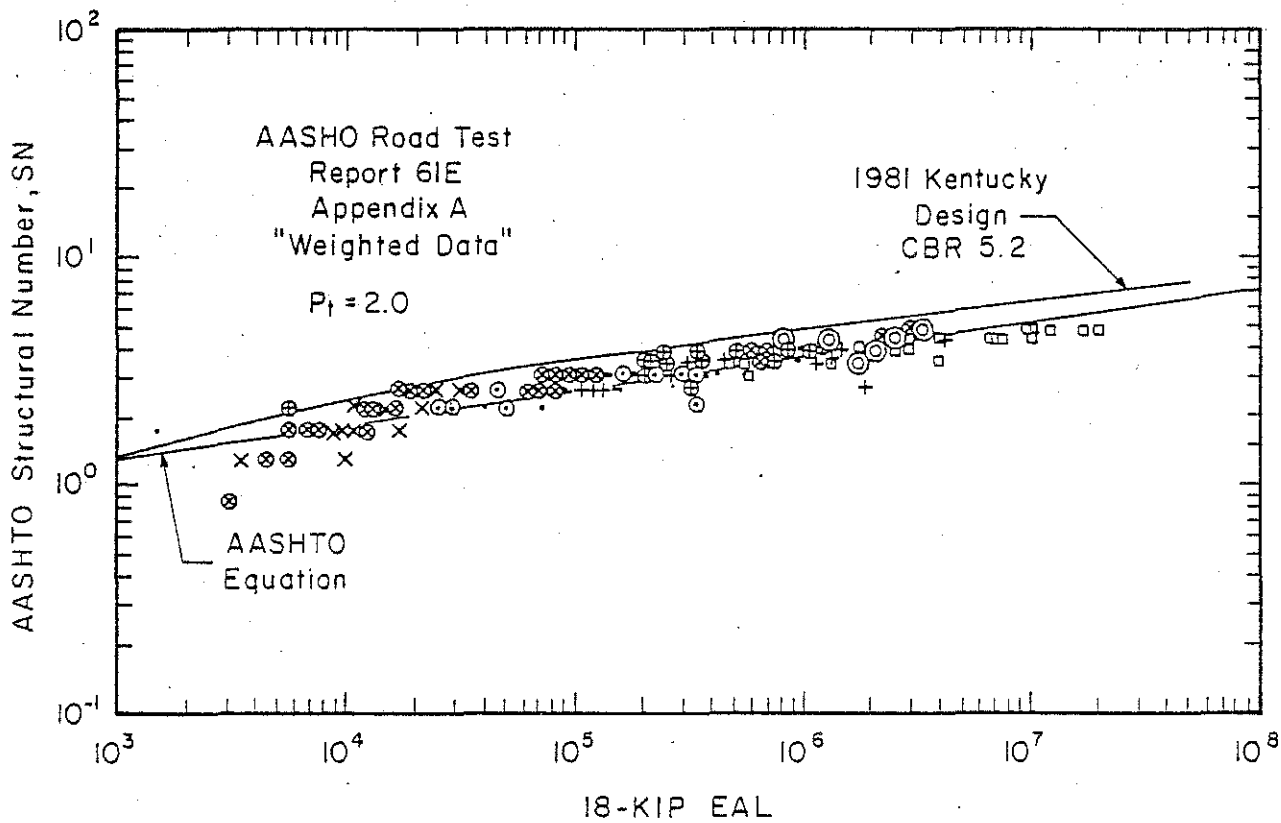FOR A LEVEL OF SERVICEABILITY OF 1.5.

FIGURE 2.   COMPARISON OF KENTUCKY DESIGN CURVE, SOLUTION OF AASHTO
             EQUATION   C-14,   AND REPETITIONS AT THE AASHO ROAD TEST
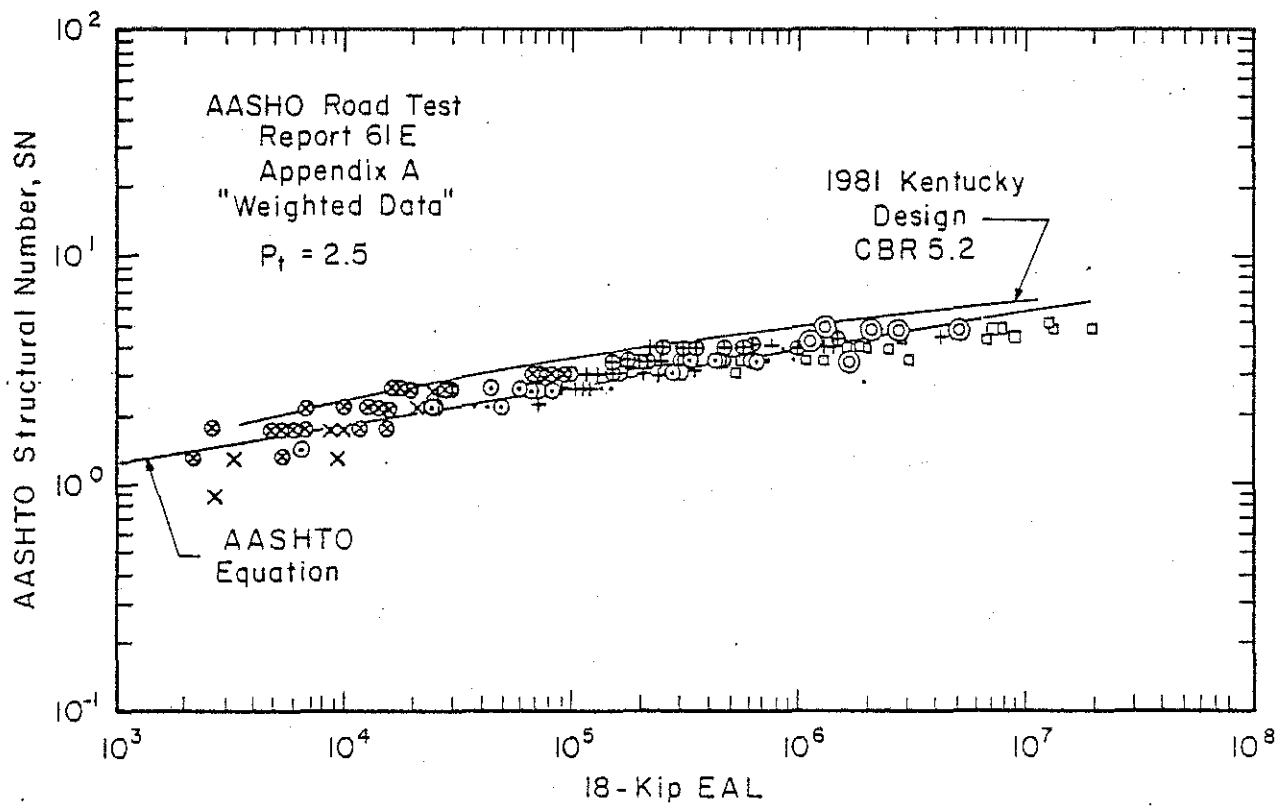   FOR A LEVEL OF SERVICEABILITY OF 2.0.

FIGURE 3.   COMPARISON OF KENTUCKY DESIGN CURVE, SOLUTION OF AASHTO
EQUATION   C-14,   AND REPETITIONS AT THE AASHO ROAD TEST
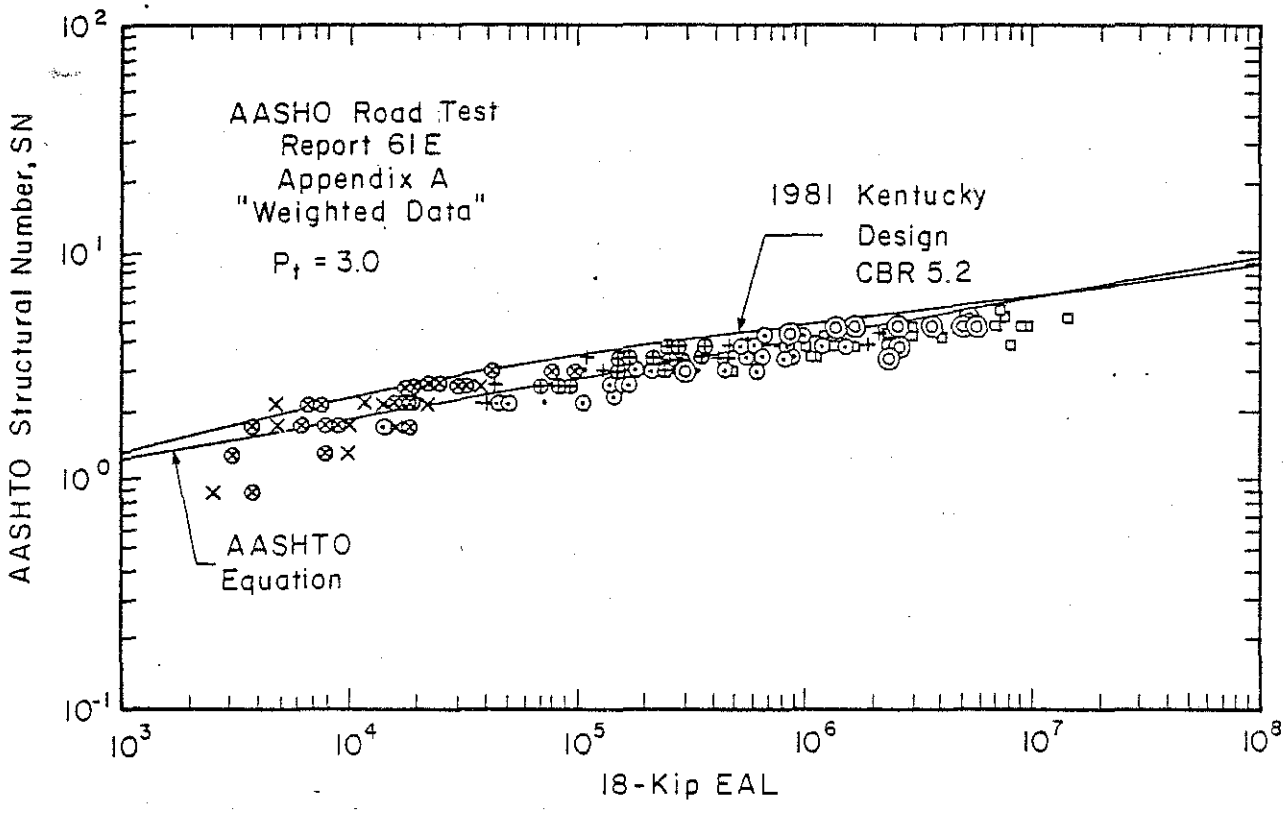FOR A LEVEL OF SERVICEABILITY OF 2.5.

FIGURE 4.   COMPARISON OF KENTUCKY DESIGN CURVE, SOLUTION OF AASHTO
EQUATION C-14,   AND REPETITIONS AT THE AASHO ROAD   TEST
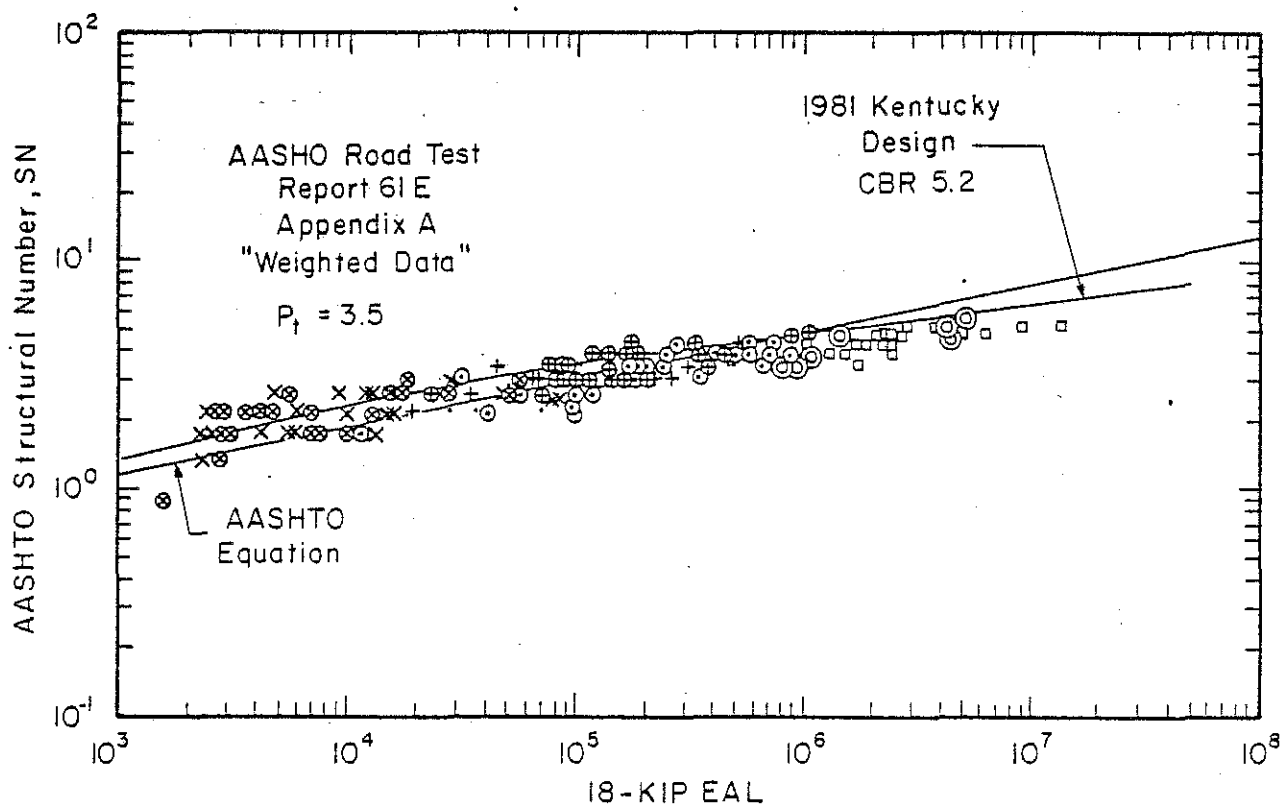FOR A LEVEL OF SERVICEABILITY OF 3.0.

FIGURE 5.   COMPARISON OF KENTUCKY DESIGN CURVE, SOLUTION OF AASHTO
EQUATION C-14,   AND REPETITIONS AT THE AASHO ROAD TEST
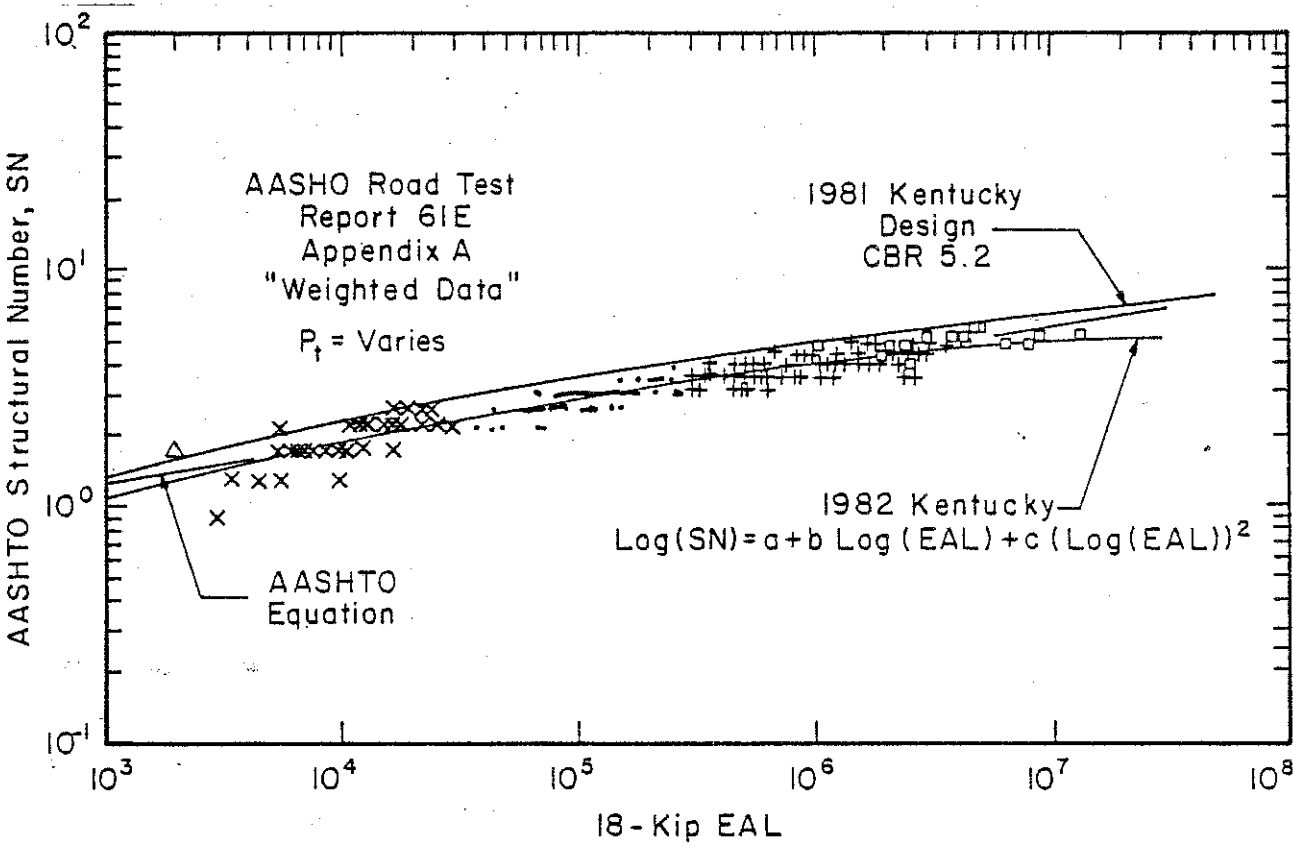FOR A LEVEL OF SERVICEABILITY OF 3.5.

FIGURE 6. COMPARISON OF KENTUCKY DESIGN CURVE TO STRUCTURAL NUMBER AFTER COMBINING LEVELS OF SERVICEABILITY.