COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

HENRY WARD
COMMISSIONER OF HIGHWAYS

June 7, 1960

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

C.2.3.
P.3.1.

MEMO TO: A. O. Neiser
Assistant State Highway Engineer

SUBJECT: Pavement Design for Interstate Highways

Following the discussion on interstate pavement design in Mr. Bray's office a month or so ago, J. H. Havens and I have prepared the attached item, "Criteria for Design of Pavement Thicknesses, Kentucky Interstate Highways".

We have tried to discuss briefly the development of the Kentucky Department of Highways' design procedures and to list applicable references. The bituminous concrete pavement section is based upon the Department's experience and empirical curves developed by the Research Division.

The portland cement concrete pavement section deals with the design procedure developed for the Portland Cement Association. The design factors used have been discussed.

You will note that the flexible designs are founded upon the equivalent wheel load method of traffic evaluation. The rigid pavement is designed upon the maximum or design wheel and axle load. The legal single axle load limit for Kentucky is 18,000 pounds, but loadometer data tabulated in Table 9, Appendix I of Reference 3, lists axles weighed in the 25,000 to 27,000-pound range. Axles heavier than the legal limit are used in the flexible pavement design traffic evaluation.

The design axle weights for rigid pavements were calculated by increasing the legal axle limit (18,000 pounds) through the use of over-load and impact factors. The impact factor of 1.5 is somewhat higher than that recommended by the Portland Cement Association Manual but we believe it to be consistent with design practices of other highway departments.

We have prepared a section listed as "Equivalency of Design" that we think should be helpful in equating traffic evaluation and pavement design. Please advise if there are any other items that you would recommend for consideration.

W. B. Drake
Associate Director of Research

WBD:dl
Encs.

CRITERIA FOR DESIGN OF PAVEMENT THICKNESSES KENTUCKY INTERSTATE HIGHWAYS

Bituminous Concrete Pavements

The Kentucky Department of Highways, in 1946, sought a more systematic criteria and basis for designing the thickness of bituminous concrete pavements. The Research Division was authorized to pursue this work and to develop the criterion. These efforts were embodied in a report (1) to the Department, which offered a system of design based upon CBR's and EWL's. EWL's were computed originally for a 10-yr. period but this practice was revised in 1954, to encompass 20-yr. traffic (more realistic with respect to average road life). Then, in 1957, the Department requested a re-evaluation of the criteria from the standpoint of experience and performance of pavements designed thereby. This re-study and recommendations was reported to the Department and to the Highway Research Board (2)(3). A copy of current design chart is shown on the following page (Fig. 20, ref. 2 and 3).

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(1) Baker, R. F. and Drake, W. B., "Investigation of Field and Laboratory Methods for Evaluating Subgrade Support in the Design of Highway Flexible Pavements," Bulletin No. 13, Engineering Experimental Station, University of Kentucky, Sept. 1949.

(2) Drake, W. B. and Havens, J. H., "Re-Evaluation of Kentucky Flexible Pavement Design Criterion," Bulletin No. 233, Highway Research Board, 1959.

(3) Drake, W. B. and Havens, J. H., "Kentucky Flexible Pavement Design Studies," Bulletin No. 52, Engineering Experiment Station, University of Kentucky, 1959.

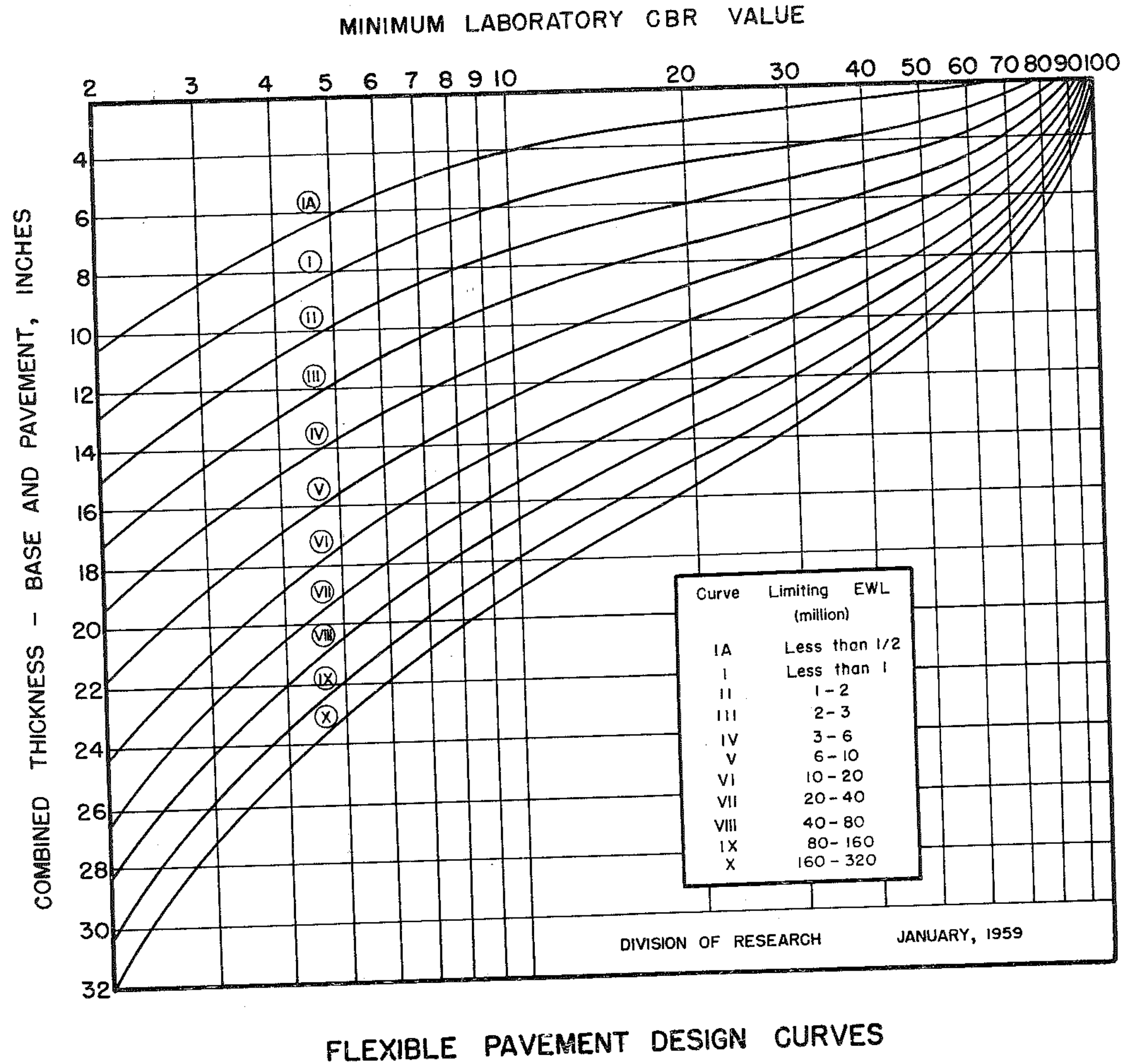

Fig. 20: Revised Flexible Pavement Design Curves.

All of the Interstate routes planned for Kentucky have existing traffic counts approaching 3000 vpd or exceeding this by as much as 12 times. Taking the 1957 state average for roads in the 3000-vpd group (see Fig. 29, (2) (3), following page), the average EWL's would be 31,691,816. However, allowing for 30% over-load for military vehicles, there would be some number of axles weighing 11.7 tons for which the multiplying factor would be 128. Assuming then, that the number of these heavy axles would be equal to the average number of axles (1957, projected 20 yrs.) exceeding 17,000 lbs., 128 x 936,272 = 119,842,816 EWL's creditable to military traffic. Adding this value to civilian traffic, yields a total EWL of 151,534,127, which is in the upper range of Curve IX of the design chart and which would require 22 in. of pavement for a CBR of 5 (Note: Appendix III, Reference 3, for thickness of component pavement parts).

Likewise, but in a very general way, EWL's increase in proportion to vpd. Thus, a 12-fold increase over the average in the 3000-vpd group would yield EWL's in the order of 380 million (31,691,816 x 12). This extreme EWL-value does not include any allowance for military over-load; but it seems impractical to design for higher values. It is reasoned, therefore, that Curves IX and X embrace the range of conditions anticipated for the Interstate system of highways.

TRAFFIC VOLUME GROUP 3000+

COUNTY ——— ROAD NAME ——— ROUTE NO. ———

PROJECT LIMITS ——— PROJECT NO. ———

LOADOMETER STATION REFERENCE *State Average 1957, Volume Group 3000-3999*

(1) Per Cent of Trucks *15.4*

(2) Average Axles per Truck *2.557*

(3) Average 24 Hour Traffic *3640*

(4) Average 24 Hour Truck Traffic = (1) x (3) *561*

(5) Average 24 Hour Truck Traffic at End of 10 Year Period = 1.465 x (4) . *822*

(6) Average Axles per Truck at End of 10 Year Period = (2) + 0.19 . . . . *2.747*

(7) Total Axles in 20 Years = (5) x (6) x 365 x 20 . . . . *16,483,650*

(A) Axle Load (Tons)	(B) Total Axles (7)	(C) % of Total Axles From Load Sta.	(D) Correction	(E) Corrected % of Total Axles (C) + (D)	(F) Total Axles by Weight Class (B) x (E)	(G) EWL Factor	(H) EWL for Two Directions
4½-5½	*Same as Item*	*5.205*	0.09	*5.295*	*872,809*	1	*872,809*
5½-6½		*4.732*	0.13	*4.862*	*801,435*	2	*1,602,870*
6½-7½		*4.732*	0.27	*5.002*	*824,512*	4	*3,298,048*
7½-8½		*4.574*	0.15	*4.724*	*778,688*	8	*6,229,504*
8½-9½		*4.101*	0.11	*4.211*	*694,127*	16	*11,106,032*
9½-10½		*1.261*	0.05	*1.311*	*216,101*	32	*6,915,232*
10½-11½		*0.158*	0.00	*0.158*	*26,044*	64	*1,666,816*
11½-12½		*0*	0.00	*0*	*0*	128	*0*

TOTAL EWL for 20 year period (two directions) *31,691,311*

Fig. 29: Sample Calculation for Estimating 20-Year EWL's, 3000 + vpd.

Portland Cement Concrete Pavements

Thickness designs for portland cement concrete pavements in Kentucky have been based largely upon the stylized criterion offered by the Portland Cement Association (4) which, of course, is founded on the work of well-known scholars. It is reasoned, however, that the suggested methods therein of determining the "controlling wheel load" and "design life" may be arbitrary and argumentive. In the applicable equation (protected corners, Formula 1), P, the design wheel load, is the design static wheel load multiplied by a judicious impact factor (see following discussion). If P is taken as the legal load limit (9-ton axle, 4.5 ton wheel load), "design life" would simply be the number of years to accumulate 100,000 or more repetitions of the legal wheel load. Under other circumstances the prevailing 100,000 heaviest wheel loads (loadometer data) might be used for design even though such a value might exceed the legal load limit. Similarly, the legal wheel-load limit might be used as a basis but with due allowances for a percentage and frequency of over-loads. Either approach should anticipate future increases in axle loads and the eventual increase in the axle loads permitted by Kentucky weight laws.

It is proposed for the design of Interstate roads: (1) that the present legal axle load limit, 18,000 lbs., be used as the basic axle load, (2) that a 30% over-load allowance for military and civilian traffic be used (18,000 x 130% = 23,400 lb. axle or 11,700-lb. wheel), and (3) that an impact factor of 1.5 be used instead of 1.2, the more common

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(4) Concrete Pavement Design..., PCA, 1951.

value, (11,700 x 1.5 = 17,550 lbs. design wheel load). Assuming a CBR of 5 (K = 150) and using a design wheel load of 17,550 lbs., yields a slab thickness of 9.6 in. which is rounded off to 10 in. (strength of concrete, modulus of rupture, assumed to be 600 psi (Kentucky Specification, Article 4.1.5D, 1956); safety factor = 2; max. working stress = 300 psi).

It may be noted that no impact factor was included in the criterion for designing bituminous concrete pavement systems. It is reasoned that the flexible pavement criterion was established from performance (empirical) and traffic data wherein impact and dynamic factors are inherently considered.

The use of the larger dynamic or impact factor is proposed partly on a judicious basis and is partly supported by research. It is widely recognized, of course, that, while it is desired that roads be built smooth and that they remain so throughout their useful life, ideal smoothness is not achieved in reality and that roughness worsens with age and use of the road. Thus, sprung loads undulate even on seemingly smooth roads and bounce as roughness increases. Nijboer (5) suggests a shock coefficient of 2(dynamic loads equal to twice the static wheel loads). AASHO (6) requires a 30% impact factor for the design of some bridges. Yoder (7) points out that an impact allowance of 20%

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(5) Nijboer, L. W.; Plasticity as a Factor in the Design of Bituminous Road Carpets, Elsevier, New York, 1948, p. 12 & 14.

(6) AASHO, Standard Specifications for Highway Bridges, 7th Ed., 1957, p. 16.

(7) Yoder, E. J.; Principles of Pavement Design, Wiley, 1959, p. 107.

(1.2) is commonly used, but he also refers to BPR tests which indicate impact due to a load passing over an obstruction to be 150% greater than the static load.

It is apparent from other studies that moving wheel loads may at times be less than static loads and at other times considerably higher than the static load. In fact, it appears that our present knowledge of this factor is rather inconclusive and that further research is needed in regard to this important aspect of pavement design. Several related additional references are offered in support of this contention, (8, 9, 10, 11 & 12).

In any case, the use of over-load factors and dynamic factors to project the present legal axle load is an expedient estimate of future trends in highway transportation. The assumption of 30% over-load (18,000 x 1.3 = 23,400) may, in fact, be a conservative estimate of future trends in axle loads. In Maryland (13), for instance, the

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(8) Bonse, R.P.H. and Kuhn, S. H.; "Dynamic Forces Exerted by Moving Vehicles on a Road Surface", Bulletin No. 233, HRB, 1959.

(9) Biggs, J.M., Suer, H.S., and Louw, J.M.; "Progress Report No. 2, Bridge Vibrations", Research Report No. 19, Joint Highway Research Project, MIT, July 1956.

(10) Gesund, Hans; "The Dynamic Response of Beams to Moving Mass Loads," Ph. D. Dissertation, Yale School of Engineering, 1958.

(11) Norman, O. K. and Hopkins, R. C.; "Weighing Vehicles in Motion", Public Roads, April, 1952.

(12) Hopkins, R.C. and Boswell, H.H.; "A Comparison of Methods Used for Measuring Variations in Loads Transferred Through Vehicle Tires to the Road Surface, Public Roads, Oct. 1957.

(13) Lee, Allen; "Experience with Flexible Pavements in Maryland", Bulletin No. 136, HRB, 1956.

prevailing legal axle load limit is 22,400 lbs., plus 10% impact factor, and special registration of dump trucks operating within a 40-mi. radius permits axles loads of 28,000 and 31,000 lbs.

This criterion further proposes the use of 6 in. of granular insulation or base under concrete pavement slabs. This practice anticipates an extreme depth of frost penetration of 18 in. or less and that a minimum of 4 in. base is needed to safe-guard against pumping. The preferred 6-in. base is in line with common practices elsewhere and with recent studies (14)(15) related thereto.

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(14) Childs, L. D. and Kapernick, J. W.; "Test of Concrete Pavements on Gravel Sub-bases", Journal of the Highways Division, Proceedings, ASCE, Paper 1800, Vol. 84, October, 1958.

(15) Colley, B. E.,: and Nowlen, J. W.; "Performance of Subbases for Concrete Pavements under Repetitive Loading", Bulletin No. 202, HRB, 1958.

Equivalency of Design

Although equivalency in design may be inferred from the foregoing criteria, mathematical substantiation is lacking. Fergus (2)(3) derived a formula relating EWL's to equivalent single axle load (basis for concrete pavement design). A slightly modified derivation is offered below as a matter of interest:

1. Axle loads, in tons (P) increase arithmetically:

$L = a + (n - 1)\, d$

a = 1st term = 5 tons (basic)

n = no. of terms

d = common difference = 1

L = last term = P

$P = 5 + (n - 1)\, 1$

$P - 5 = n - 1$

2. Both EWL's and California Factors increase geometrically:

$L = a\, r^{n-1}$

L = last term $\qquad L = a(2)^{n-1}$

a = 1st term = k (basic); $n - 1 = P - 5$

r = common ratio = 2

thus:

$$\text{EWL's} = k(2)^{P-5}$$

and:

$$f = k'(2)^{P-5}, \quad k' = 1 \text{ (basic)}$$

3. Since:

$$\text{EWL} = \bar{n}\,\bar{f} = \sum n_1 f_1 + n_2 f_2 \ldots$$

$$\text{EWL (millions)} = \bar{n}\,(2)^{P-5}$$

Therefore, if it is assumed that 256 million EWL's (mid-value of Curve X) is equivalent to a 24,000-lb. axle load (18,000 legal axle x 1.3 over-load = 23,400 lbs. (static) or 35,100-lbs. (dynamic), basis for portland cement concrete pavement design), then:

$$256 \times 10^6 = \bar{n}\,(2)^{12-5}$$

$$\text{and } \bar{n} = 2 \times 10^6$$

It follows, then, that all other axles and EWL's may be equated similarly (2 million EWL's = 10,000 axle load) and that equivalent design thicknesses may be interpolated from the respective design charts. Although a true basis for adjudging equivalency in designs has been and is desired, it must be recognized that the above derivation is based upon an assumed equivalency, i.e. 256 million EWL's = 24,000 lb. static axle or a 35,100-lb. dynamic axle.