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DEPARTMENT OF HIGHWAYS
FRANKFORT, KENTUCKY 40601

ADDRESS REPLY TO

H.2.20

MEMO TO: A. O. Neiser, State Highway Engineer
Chairman, Research Committee

DATE: December 31, 1968

SUBJECT: Proposed Criterion for the Design of Flexible Pavements

Our recent report on "Rational Analysis of Kentucky Flexible Pavement Criterion," November 1968, presented theoretical treatments of current design curves - which enabled transformation of the current curves into companion sets of curves embodying alternative proportions of bituminous concrete and dense-graded aggregate base. We are privileged now to submit additional analytical information and to offer recommendations for revising the present design criterion.

Certain analyses were unfinished when the above-cited report was issued. The unfinished work has been completed and extended. Specifically, reconstitution of design curves on the basis of AASHO load-equivalency factors (cf, Figures 5 and 6, p. 11, op. cit.) was conspicuously abandoned; the curves completed then were based solely on the Kentucky load-factors as originally adopted from the California criterion. We had previously declared our intention to adopt the load-factors which evolved from the AASHO Road Test. Through some foresight and good fortune, we had completed a study earlier which enables this transition to be made insofar as predicting traffic parameters is concerned. That report (Determination of Traffic Parameters for the Prediction, Projection, and Computation of EWL's;" Deacon and Lynch, August 1968) was compelling upon us to complete the AASHO-based graphs and to evaluate them as we had the curves that were actually completed and in our previous report. As stated, that has been done; a draft of a proposed design criterion - including the AASHO-based curves - is submitted for your review and consideration.

We have not had an opportunity to document the details of the continuation phase in a formal report. However, the base graphs furnished herewith provide the essential details. Additionally, we are including some "stylized" design curves which moderate the severe "anti-rutting" regions of the graphs. It will be interesting, perhaps to compare this array of curves with both the 1958 and 1949 design curves.

We believe that the "stylized curves" will be preferred.

Respectfully submitted,

Jas. H. Havens
Jas. H. Havens

Director of Research

JHH:em
Attachments
cc: W. B. Drake

FLEXIBLE PAVEMENT DESIGN CRITERION

In order to determine pavement thicknesses from the design charts (see Figures 1 through 4), it is necessary to know only the EAL's and the CBR of the subgrade soil. The respective charts permit selection of pavement structures employing alternative proportions of bituminous concrete and crushed stone base. Total thickness varies according to the proportion chosen. However, the choice may not be made arbitrarily or trivially. It is implicitly intended that the final selection be based on other engineering considerations such as:

1. Estimates of comparative construction costs,
2. Compatibility with cross section template and shoulder designs,
3. Uniformity or standardization of design practices,
4. Highway system classification,
5. Engineering precedence,
6. Utilization of indigenous resources.

The design chart based on the 1:2 proportions of bituminous concrete and crushed rock base conforms with the Department's current design chart; it therefore represents current, conventional, or precedential designs. The companion charts represent theoretical extensions of conventional designs and, from a theoretical standpoint, provide equally competent structures; however, they may not be employed with the same degree of confidence attributable to conventional designs -- this is a precautionary interjection inviting attention to the fact that the alternate designs are not supported by equal precedents.

Design EAL

Heretofore, the Kentucky design system was based on EWL's. The present system is based on EAL's. This transformation was made for the sake of unifying design practices and standardizing design terms -- from the standpoint of definition of terms. EAL's are defined here as the number of equivalent 18-kip axleloads (cf, "AASHO Interim Guide for the Design of Flexible Pavement Structures," AASHO Committee on Design; October 12, 1961).

Basically, the computation of EAL's involves first, a forecast of the total number of vehicles expected on the road during its design life; and, second, multiplying factors to convert total traffic to EAL's. Of course, this is obviously an extreme simplification. More ideally, the yearly increments of EAL's could be calculated and summed; this approach would permit consideration to be given to anticipated changes in legal weight limits, changes in style of cargo haulers, and future changes in routing.

Normally, traffic volumes are forecast in connection with needs studies and in the planning stages for all new routes and for major improvements of existing routes. Whereas anticipated traffic volume is an important consideration in the styling and geometric design of a roadway, the composition of the traffic in terms of axle weights and lane distributions

is essential to the structural design of the pavement. Traffic volumes used for EAL computations should therefore be reconciled with other planning forecasts of traffic. Historically, actual growths of traffic have exceeded the forecasts in the majority of cases. Overriding predictions of traffic volumes may be admissible for purposes of EAL estimates when properly substantiated. Moreover, the design life of the pavement may differ from the geometric design period.

Design CBR

CBR test values reflect the supporting strength of soil. Moreover, the test procedure intentionally conditions the soil – by soaking – to reflect its least or minimum supporting strength; this is presumed to be representative of the soil strength during sustained wet seasons when the ground is saturated or nearly so. At other times, the soil may be much stronger; and pavements thereon would be capable then of withstanding heavier loads. If pavements were not designed for the minimum capabilities of the foundation soil, it would be necessary to impose further restrictions seasonally on axleloads in order to prevent premature failures.

The CBR value does not assure immunity against frost-heave; although, it does have a compensating effect in the design of the pavement structure. Greater pavement depths are required for low-CBR soils than for high-CBR soils; and it is usually the low-CBR soils that are more sensitive to frost. Usually, it will not be found economical or practical to eliminate frost-sensitive soils. Very high-type pavements are normally of sufficient thickness that the supporting soil lies below the freezing line. Of course, this is not true for thinner pavements; therefore, the type of pavement structure providing the greatest template depth is preferred. Pavements less than six inches in thickness should be regarded dubiously from this point of view.

Annotated Procedure

I. Select a tentative design period (and design life); show inclusive dates.

Note 1: The design period is the inclusive dates; the number of intervening years in the design life.

Note 2: The design life normally shall be considered to be 20 years. Pavements may be designed for ultimate 20-year life but “stage” constructed; for instance, the initial stage might be based on a 10-year design period. Low class roads may be stage designed or merely designed for a proportionately shorter life. Usually it will not be practical to design pavements for low class roads to last 20 years. Economic analysis or limitations of funds may dictate the design period. In any case, the design period should be documented and justified.

Note 3: Staged designs may require commitments of funds or other assurances that succeeding stages will be constructed.

II. Obtain route description and relevant traffic volume information.

Note 1: If only the beginning and 20th-year AADT's are furnished, it may become necessary to request a listing of AADT's estimated for each calendar year – otherwise a normal growth curve must be assumed. In the absence of specific guiding information, a constant, yearly increase factor may suffice – typified by the compound interest equation $A = P(1 + i)^n$; where A = AADT in the n th year, P = the beginning AADT, i = yearly growth factor, and n = the number of years from the beginning. Thus, the AADT for each year may be calculated and then summed through n years, or an “effective” AADT may be calculated by $(P+A)/2$ – which, when multiplied by the number of years, yields the same results. In this way, errors inherent in the use of the long term average or “effective” AADT in making computations for fractional design periods may be avoided.

Note 2: AADT's are normally based on two-direction traffic volumes whereas they could be reduced to one-direction only (divided by 2, unless there is reason to suspect directional inequality). It is necessary - because of previous precedents which are yet respected in the stylized method of estimating EAL's - to compute two-direction EAL's and to adjust those values to a single-lane basis. When dual lanes in each direction are involved, it is reasonable to assume that 85% of the traffic uses the outer lanes. Whereas two-direction AADT's might be so reduced at this stage, the methodology does not permit it to be done. Instead, the directional factor and the lane-distribution factor may be applied only to the gross EAL estimate (see Note 2, under III).

III. Determine modified AASHO EAL's in accordance with Appendix F of "Determination of Traffic Parameters for the Prediction, Projection, and Computation of EWL's," by J. A. Deacon and R. L. Lynch, Division of Research, August 1968.

Note 1: This is a highly simplified procedure which involves subjective weighting factors. Additional weighting may be injected by performing the computations in fractional periods during which the subjective factors are presumed to remain constant and then altering the factors as necessary in succeeding periods. Likewise, an overriding increase or decrease in AADT could be treated in this way.

Note 2: The EAL's so determined are gross, two-directional values; this must be reduced to a one-direction basis - that is, divided by 2. When dual lanes are involved in each direction, the one-direction value should be further reduced to 85%. This reduction is based on the assumption that 85% of the traffic will use the outer lane; in the event that a more valid distribution factor becomes available, it should be used preferentially. When more than two lanes in each direction are involved, additional factors appropriating EAL's amongst the lanes will be necessary. No guiding values may be cited, but such values should be available from the respective, enabling, planning study report. The necessity of these factors is apparent: it is customary to design all lanes like the most critical one - the validity of this practice may be regarded dubiously.

IV. Analyze soil survey information and resolve design CBR values for project or sections therein.

Note 1: Ideally, analyses of soil surveys and explorations reports will not only assure rejection of soils ineligible for service as subgrade (foundation under pavements) but may enable some additional selectivity of the more competent soils. Soils having high CBR's may even be reserved from cuts and used as the final life throughout a section of roadway; however, because of the necessity for stockpiling and double handling, this may not always prove to be economical. For example, if the thickness required for a CBR 2 were 3 inches greater than for a CBR 3.5 and if the CBR-2 material were at hand, the cost of the additional 3 inches might be in the order of: 1 inch Class I base at \$.39 + 2 inches DGA at \$.17 = \$.73 per square yard (exclusive of added template effect on cost of shoulder paving); 12 inches of the lower quality subgrade soil thereunder, based on \$.69 per cubic yard for roadway excavation, would be: $1/3 \times 3/4 \times 1/2 \times $.69 = $.08$ - making the total additional cost \$.81 per square yard of pavement. If the CBR-3.5 soil were to cost \$3.50 per cubic yard (estimated as Barrow Excavation), the comparative cost per square yard would be: $1/3 \times $3.50 = 1.17 , and it would not be economical to design for the higher quality foundation soil. If the unit cost estimates differed from those cited or if the CBR of the selected soil were higher than the value assumed here, cost comparison might be favorable toward the selected subgrade material. It is recommended, of course, that the designer

consider the comparative costs of design alternatives and exercise due judgment in all subjective analyses.

- Note 2: Soil surveys may indicate wide variations in CBR's along the length of a specific project route. It is presumed and premised that adequate pavement thicknesses will be provided throughout the project. The designer must, therefore, consider the contiguity of the soils and perhaps sectionalize the project according to minimum CBR's. An analog graph may be helpful. The designer must respect all minimums or else some sections of pavement will be "under designed;" "over designs" must be admitted as a natural consequence therefrom. Here again, subjective judgment is admissible: consider two high-CBR sections having relatively long lengths separated by an intervening, short section having a low CBR. There, the designer is privileged to decide whether to require the low-CBR section to be "upgraded" to the same quality as the abutting high-CBR sections or make a separate design for the low-CBR section. Of course, the designer should consider the relative economics of the two alternatives, but he may also consider continuity and uniformity of pavement section and construction control as pertinent factors. Usually it will be found impractical to vary the design thickness within short distances.
- Note 3: It is recommended that soils having CBR's of less than 2 be considered ineligible and unsuitable for use as pavement foundation.
- Note 4: It is preferred that test values of CBR's be determined and so reported as the bearing ratio at 0.1 inch penetration.

V. Determine alternative, 20-year design thicknesses from respective graphs (Figures 1 through 4); interpolate as necessary; thicknesses read should then be rounded off to the next greater 1/2 inch. If design life of less than 20 years is to be considered or if "staged" design and construction is envisaged, determine EAL's for the respective design periods and read corresponding thicknesses. Analyze the several alternatives from the standpoint of engineering and economic feasibility.

- Note 1: Alternatives excluded by policy or predisposition should be omitted at the outset unless there is some likelihood that the analysis might prove to be persuasive or preemptive.
- Note 2: Surface renewal for de-slicking or protecting an otherwise adequate pavement structure during a 20-year tenure in service is highly probable; leveling courses may be needed to compensate for settlement and subsidence. "Staged" design and construction offers off-setting benefits. Whereas surface renewal and wedging are accounted as maintenance, staging should be conceived not as a disguised form of maintenance, but rather as an alternative to be evaluated and employed if found advantageous.
- Note 3: Whereas the respective sets of design curves (solid black) provide equal assurances against rutting throughout all ranges of EAL's, greater rutting is tacitly and progressively admissible in some inverse relationship to EAL's. It has been presupposed that no additional rutting should be allowed in Curves IX, X, XI, and XII. On the other hand, it seemed that Curve IA pavements might be allowed to rut in a completely uncontrolled manner. Weighting the intervening curves in relationship to EAL's permitted construction of guide curves through the regions of the graphs where rutting criteria control. It is suggested that these curves be respected in an advisory way. They may be violated permissively in either direction -- provided the fatigue limit of the asphalt layer is respected.

Note 4: Neither the design charts nor the EAL parameters is discretely applicable to the structural design of shoulder pavements. Shoulder pavements, in one sense, are analogous to "hard stands;" in another sense, they might be compared to low-class roads. Curve IA (equivalent to 1.07 18-kip axles per day or 7,800 repetitions in 20 years) may result in "over design." On the other hand, if it were necessary to divert main-line traffic onto the shoulder to do maintenance on the main line, the 20-year quota of repetitions might be accumulated in a few days. For this reason, the design should include some reserve capabilities. However, in the absence of more definitive criteria, it is suggested that Curve IA be used for guidance. Further reductions in thickness may be justified on the basis that shoulders are repairable.

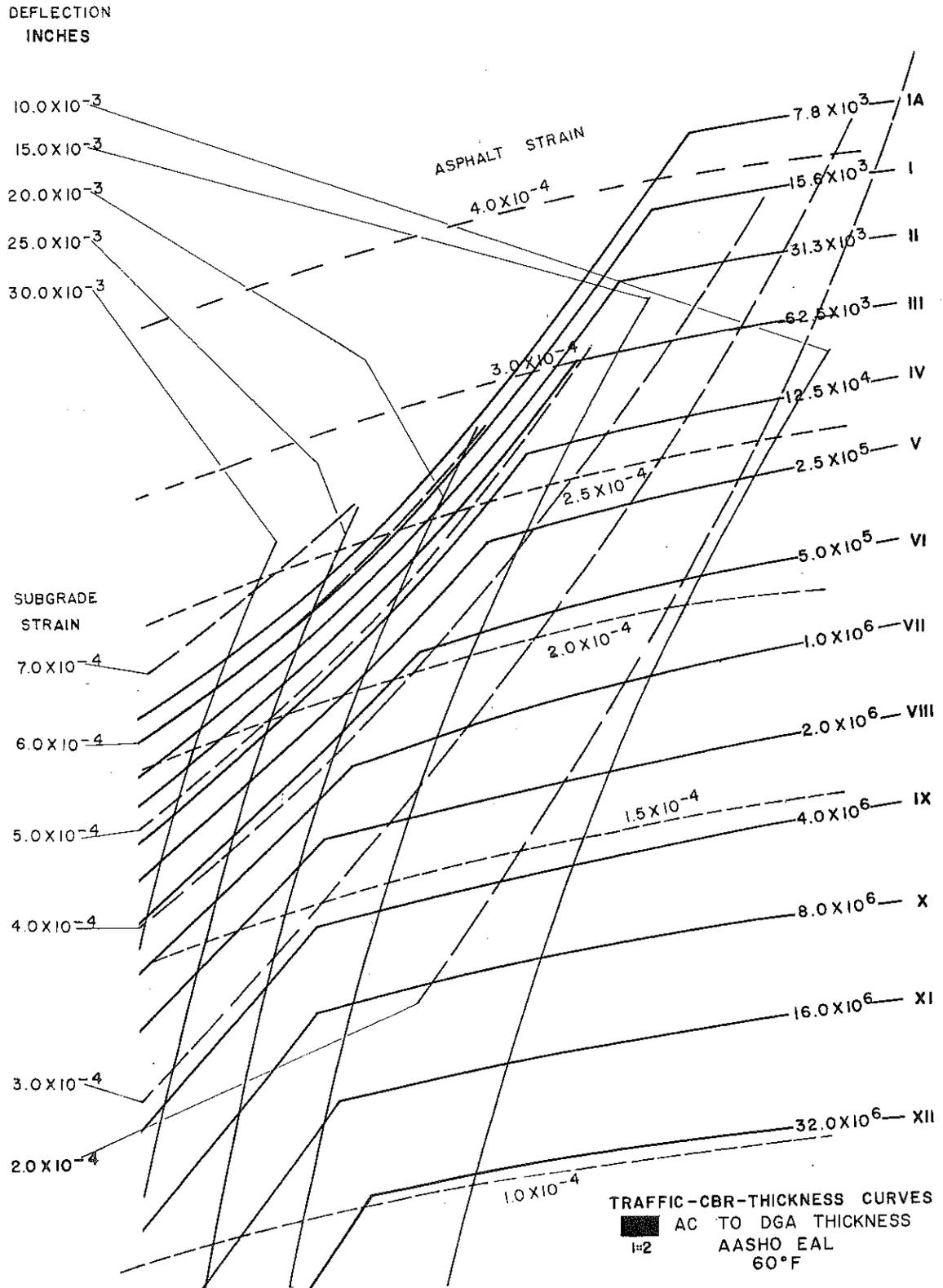


Figure 1

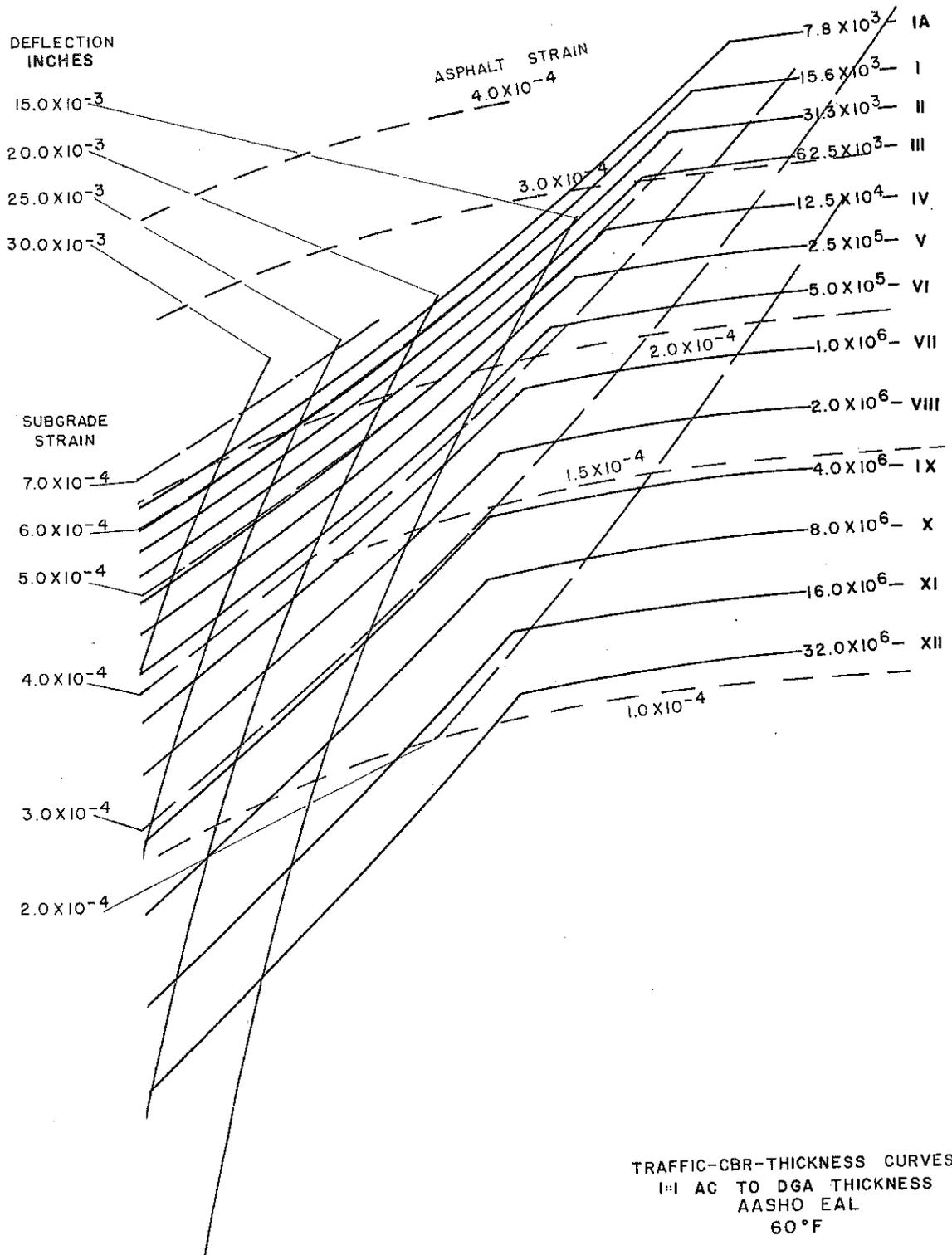


Figure 2

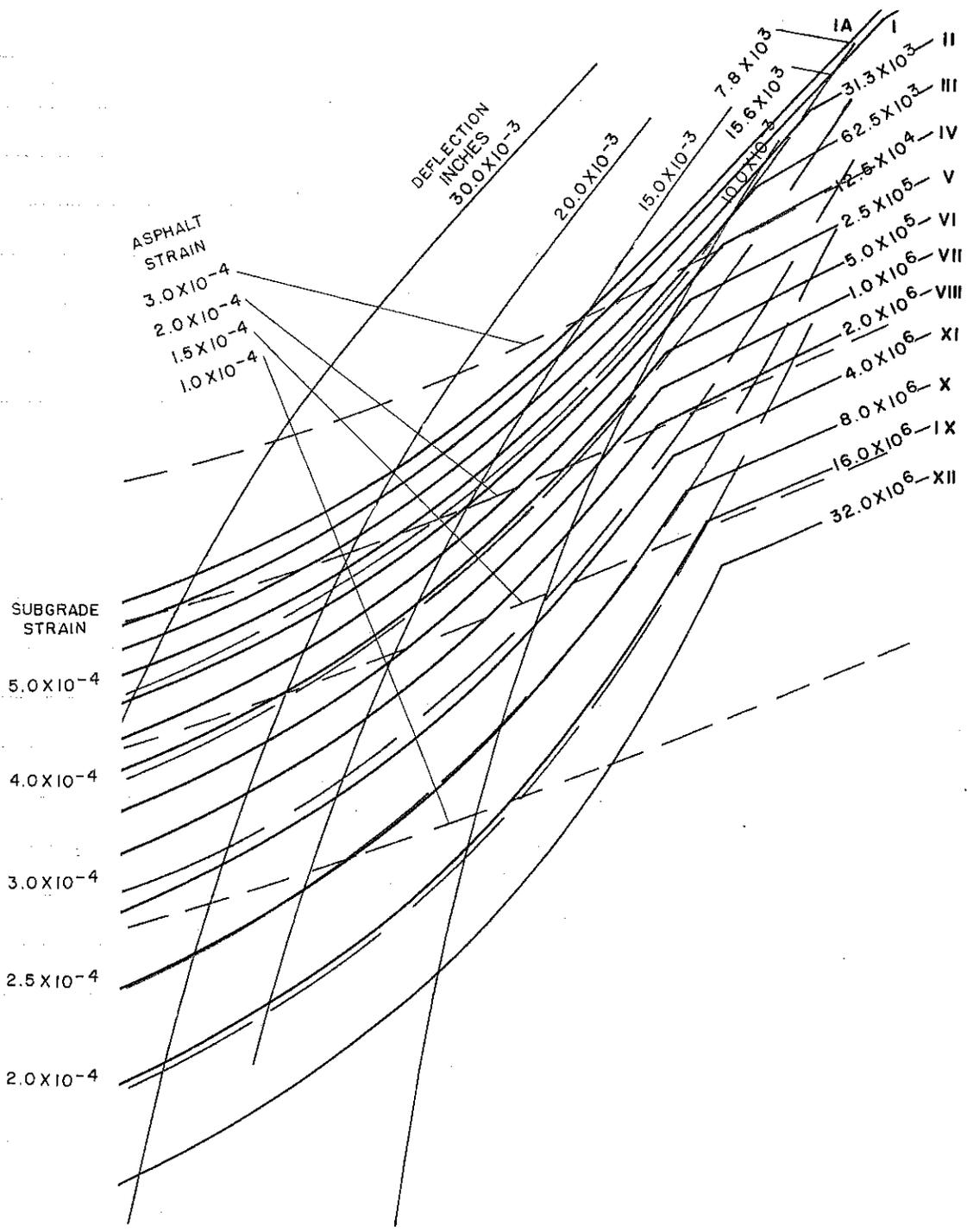


Figure 3

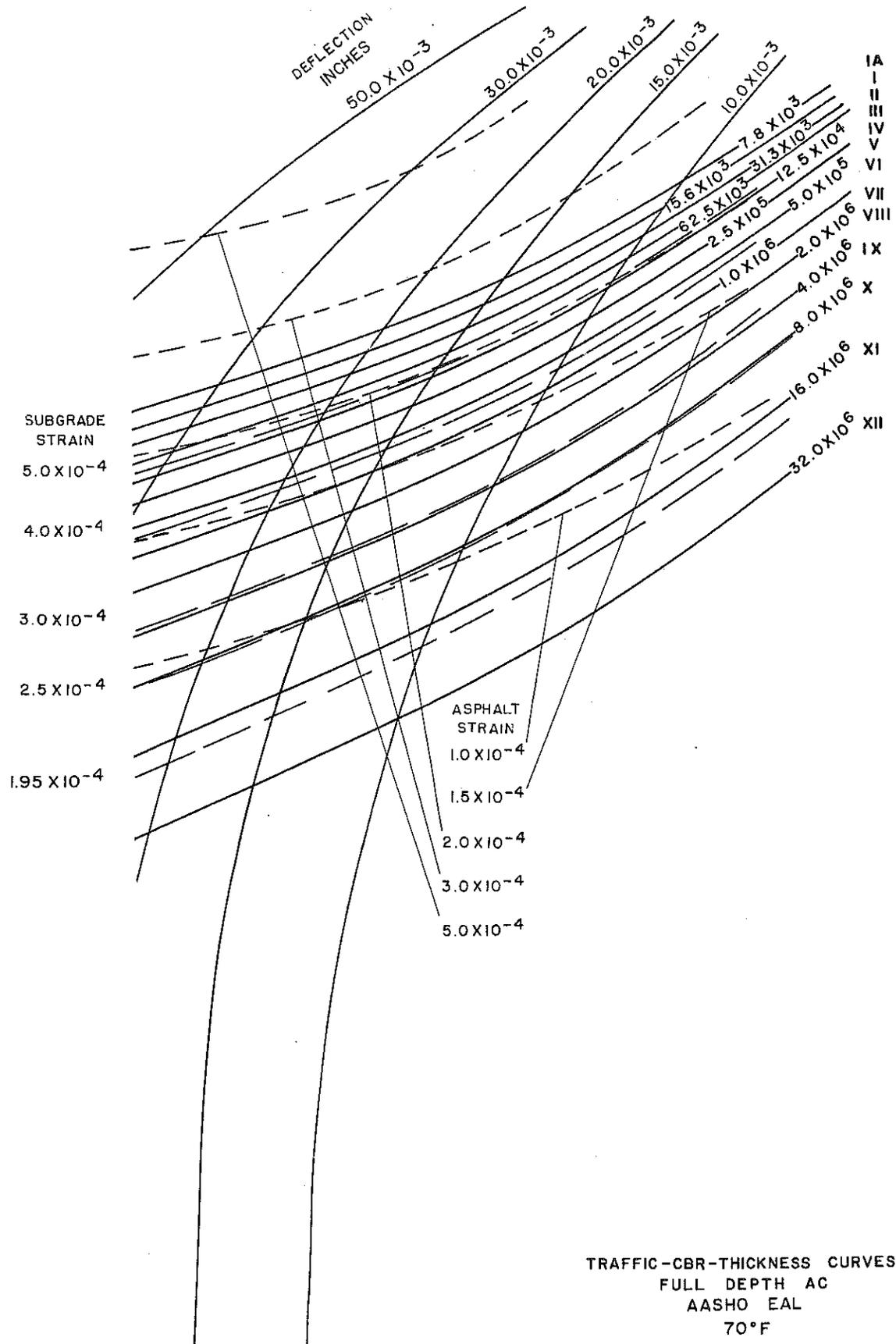
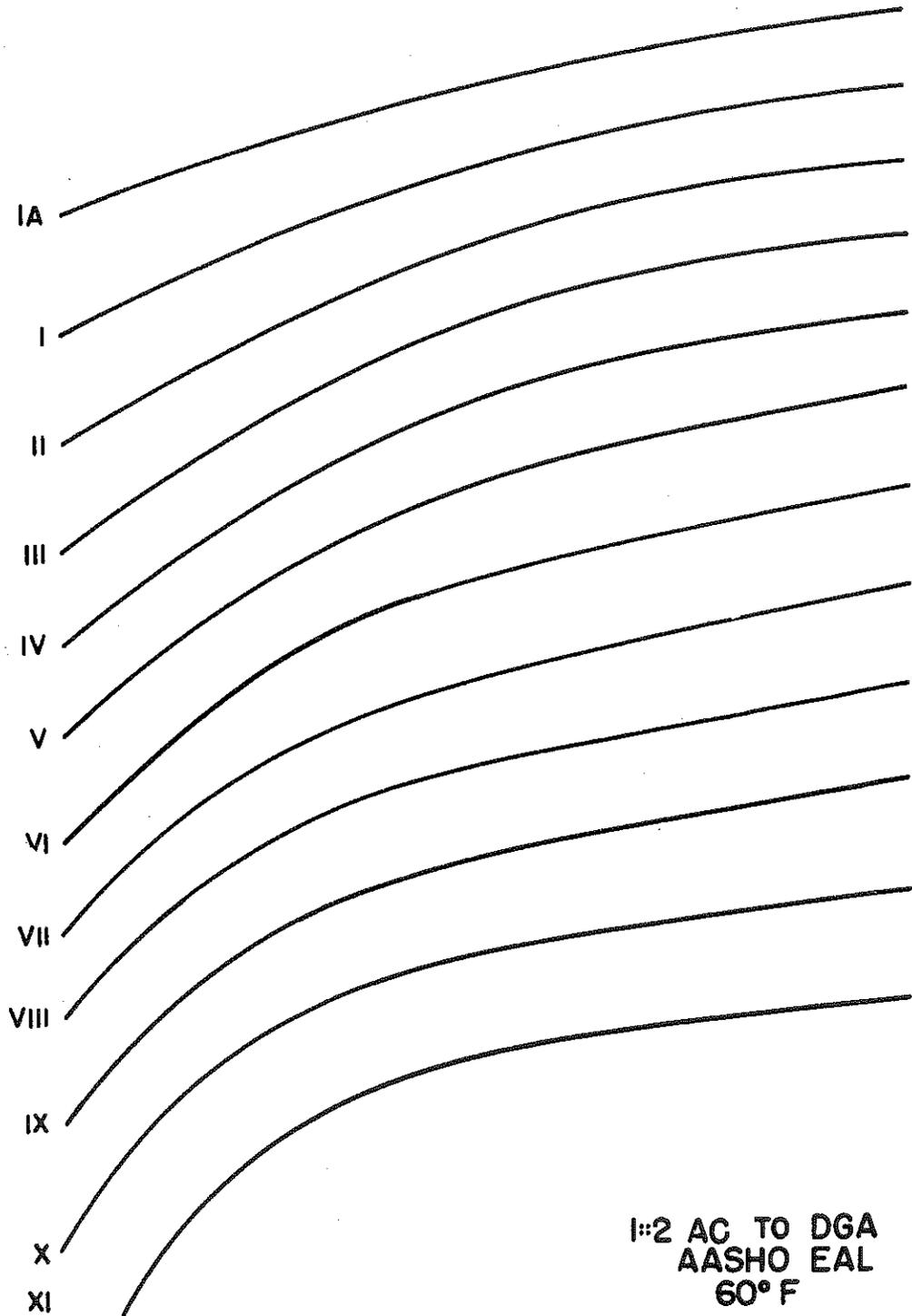
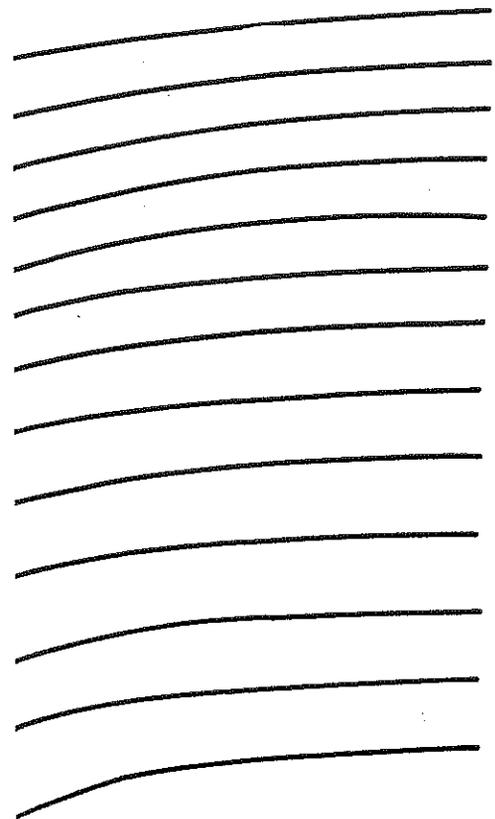


Figure 4

STYLIZED DESIGN CURVES

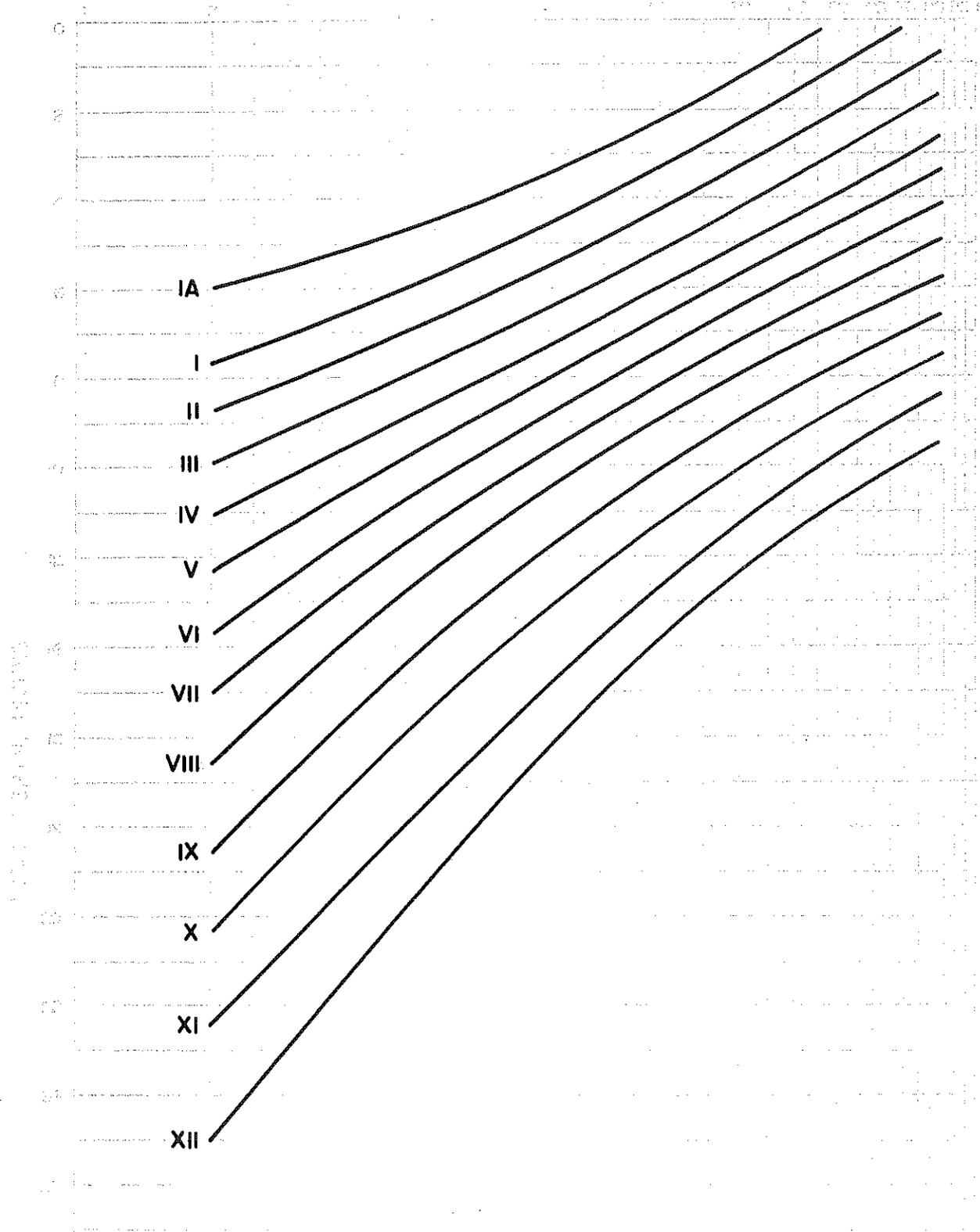




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AASHO EAL
60° F

STYLIZED DESIGN CURVES



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AASHO EAL
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