bols are used to reflect the soil properties under such conditions. These F and R symbols are used to evaluate the various classes of soil as subgrade supporting material under varying conditions of moisture and frost and in determining from design curves thickness of pavement required for flexible (F) and rigid (R) pavements. Thus an E-1 soil is evaluated as a F_a or R_{1a} material on which no sub-base would be required under any conditions. An E-3 soil is an estimate of the poorest soil on which a base course for a flexible pavement could be placed under the most favorable conditions of no frost and good drainage and is evaluated as an F_a material for these conditions, but as an F_1, F_2, or F_3 material requiring sub-base of increasing thicknesses for conditions of severe frost-good drainage, no frost-poor drainage, and severe frost-poor drainage, respectively. Likewise, an E-5 soil characterizes the poorest material on which a rigid pavement could be placed without a sub-base for conditions of no frost, and under such conditions is evaluated as an R_{1a} material; while for frost conditions this E-5 soil is evaluated as R_{2b} requiring sub-base.

This method of soil classification has been in use for only 7 months and undoubtedly as additional information is assembled, revisions and adjustments will be found desirable. Classification of soils on all new projects, as well as on airports and landing fields already constructed, will result in sufficient information so that eventually the soils classification values can be adjusted to meet our requirements for design.

DISCUSSION

Application of the Classifications and Group Index in Estimating Desirable Subbase and Total Pavement Thicknesses

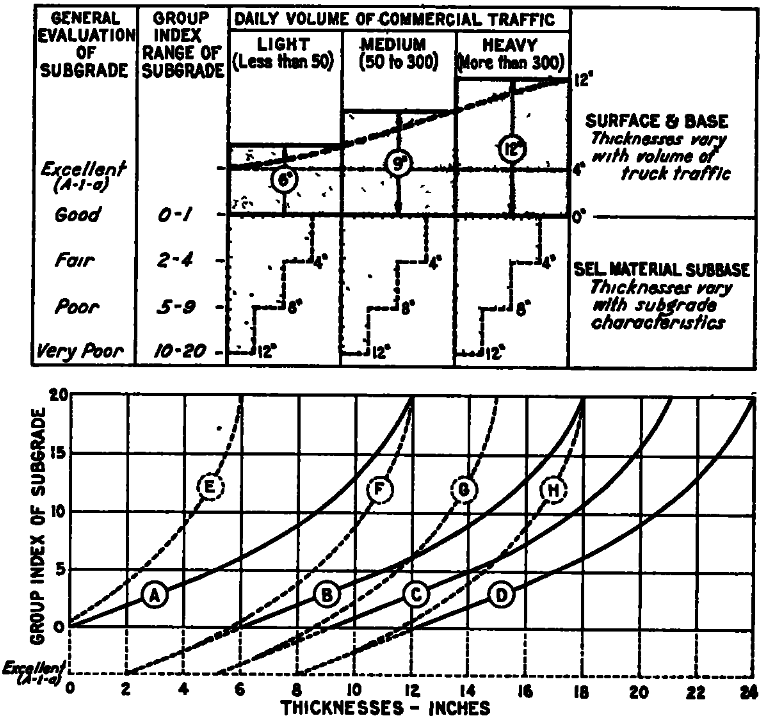
D. J. Steele, *Materials Engineer, San Francisco District, Public Roads Administration.* Under the heading "Subbase Thicknesses" the report lists several variables, in addition to properties of subgrade, which should be taken into account in designing thicknesses. The recommended procedure for arriving at adequate and economical foundation designs for a particular area is to identify subgrade types, determine thicknesses and types of existing pavements over these subgrades, and evaluate past performance with due regard for the traffic and other variables mentioned. However, the report recognizes that empirical thickness tables tied to test values may be helpful if applied to local conditions under competent engineering direction.

I have been requested to discuss and present examples of empirical thickness tables tied to the test methods and classification arrangement of the report. This assignment is accepted with some hesitancy as, firstly, it must be admitted that there are inadequacies in all presently known subgrade identification and test methods and, secondly, there is danger that any set of thickness tables or curves will be taken too literally without the adjustment to local conditions and performance which the report recommends and which requires the kind of engineering experience and skill not replaceable by tables or curves. Nevertheless, even approximately correct evaluation of test data on subgrades and local materials results in more nearly correct design than is possible without such evaluation. Therefore, the writer is presenting an outline which his experience indicates as approximating desirable practice under average conditions, and with the full expectation that those who take the trouble to check it against actual performance of existing roads in various localities will find it less than a perfect answer to an exceedingly complex problem.

The essentials of the outline are shown by the charts of Figure A. These charts purport to take care of three of the six variables mentioned in the report; subgrade characteristics, traffic, and justifiable factor of safety on basis of availability of satisfactory subbase materials The three other variables mentioned are discussed as follows:

Climate—It is considered that the over-all thicknesses shown by the charts should take care of most variations in climatic conditions, the probable exception being the effect of deep frost penetration. Counteracting the effects of frost penetration apparently involves provision for good drainage combined with use of subbase and base materials which are not weakened appreciably by alternate freezing and thawing, and solution should be based on local experience.

Drainage Conditions—It is assumed that subgrade will be sufficiently above any water table to permit proper consolidation of the subgrade prior to placing base or subbase and that



Curve A.- Thicknesses of Selected Material Subbase only
" B - Combined Thicknesses of Surface, Base & Selected Material Subbase - Light Traffic
" C- " " " " " " " " " " Medium
" D- " " " " " " " " " " Heavy
" E - Thicknesses of Additional Base which may be substituted for Subbase of Curve A.
" F - Combined Thicknesses of Surface and Base (No Subbase) - Light Traffic.
" G " " " " " " " " " Medium "
" H " " " " " " " " " Heavy "

Figure A. Charts showing an approximation of desirable total pavement thicknesses (surface, base and subbase) based on truck traffic volume and group index of subgrade. (See discussion for Explanations, Assumptions and Exceptions.)

Degree of Construction Compaction—The charts are based on the assumption that subgrades will be reasonably well compacted prior to placing of subbase or base thereon, say, not less than 95 per cent of maximum density as determined by A A S H.O. Method T-99-38, and that subbase and bases will be well compacted to, say, not less than 100 per cent of such density.

under-drainage or sufficient embankment height will be provided where necessary to keep ground water tables at least 3 or 4 ft. below pavement surface

The upper chart of Figure A is an attempt to show graphically the conception that, for roads which are to have paved surfaces and which will carry at least some vehicles of maximum legal wheel-loads (9000 lb ±), the required subbase treatment will vary only with subgrade characteristics, while the required thicknesses and types of base and surface will follow generally current practice and vary with the expected volume of truck traffic.

For the purposes of designing total pavement thicknesses the left-hand column of the upper chart divides subgrades into five general classes as follows:

Excellent—This includes natural gravelly materials which are equivalent to high-quality granular base materials and on which all or part of the granular base element of the pavement designs hereinafter discussed may be omitted. These materials are here identified as those falling in group A-1-a of the classification This identification may be too restrictive under some conditions and not sufficiently restrictive under others, but it will serve the purpose here with the understanding that specifications for granular base materials known to be satisfactory for the purpose may be substituted therefore in actual practice.

Good—This includes the common run of fine sands, silty sands and silty or clayey gravels which are identified in the second column of the chart as having group index of zero with a tolerance of one. Excepting the "Excellent" materials above discussed, these materials will usually fall in groups A-1-b, A-3 and A-2, although the tolerance of one will permit inclusion of borderline granular materials falling in other groups. These "Good" subgrades do not required subbase under the base and surfaces courses hereinafter discussed.

Fair—This includes the silty and clayey sands and gravels which are borderline between groups A-2 and A-4, A-5, A-6 and A-7 and which are identified in the second column of the chart as having a group index range of 2 to 4 These "Fair" subgrades should be covered with about 4 in of "Good" selected material subbase (or granular base thickness should be increased).

Poor—This includes the typical silty materials of groups A-4 and A-5 and some of the gravelly or sandy clays falling in groups A-6 and A-7. These materials are identified in the second column of the chart as having group index range of 5 to 9. These subgrades should be covered with about 8 in. of selected material subbase, the lower 4 in. of which should be of at least "Fair" quality and the upper 4 in should be of at least "Good" quality (or granular base thickness should be increased).

Very Poor—This includes the elastic silts, silty clays and clays of groups A-5, A-6 and A-7 which are identified in the second column of the chart as having a group index range of 10 to 20. These subgrades should be covered with about 12 in of selected material subbase, the lower 8 in. of which should be of at least "Fair" quality and the upper 4 in. should be of at least "Good" quality (or granular base thickness should be increased). It is important that the lower layer of subbase or base placed contiguous to this type of subgrade contain sufficient sand sizes to prevent infiltration of the clay soil into the subbase or base.

The general evaluation of subgrades as Excellent, Good, Fair, Poor, and Very Poor with identification by classification or group index is considered advantageous in that other combinations of test values could be introduced in identifying the five general subdivisions without changing the general framework set up for arriving at the approximate required thicknesses of subbase or additional base. It is not intended to suggest that these general evaluations should displace the group classifications A-1 to A-7 as included in the report The group classifications are desirable for indicating the types of subgrade materials, even though the group index or other test result combinations may be the basis of evaluating supporting power

The combined thicknesses of surface and base courses set up on the upper chart as varying, with expected volume of truck traffic, from 6 in. for "Light" traffic to 12 in. for "Heavy" traffic are arrived at on the assumption that natural subgrade will be "Good" or that subbase or additional thickness of base will be provided over "Fair", "Poor", and "Very Poor" subgrades as discussed. The thicknesses are also premised on the assumption that it is advantageous to include a high-quality granular base of about 4 in. minimum thickness except where the subgrade or subbase is "Excellent" and approximately of base course quality. While it is beyond the scope of this discussion to go into the many variables which must be considered in the design of surface courses, it appears necessary to describe at least a few common combinations of surface and base for different truck traffic volumes in order to make clear what is intended by thicknesses shown on the charts. These examples are as follows

Light Traffic—Typical designs would include a surface treatment on 6-in base or a 2-in. bituminous mix on 4-in. base. If the subgrade is "Excellent" and reasonably free of oversize stones, a satisfactory surface might be obtained by surface treatment or mixing a thin layer of the native subgrade with bituminous material.

Medium Traffic—Typical designs would include 2 to 4 in asphaltic mix on 4-in granular base, or say, 3 in of asphaltic mix or macadam on 6-in granular base If the subgrade or subbase is "Excellent" all or a portion of the granular base could be omitted.

Heavy Traffic—Typical designs would include 4 to 6 in. of asphaltic concrete on 6-in. granular base, or for very heavy volume of truck traffic, say, 8 in ± of portland cement concrete on 4-in. granular base If the sub grade or subbase is "Excellent" all or a portion of the granular base could be omitted.

It is to be noted that Figure A defines "Light", "Medium", and "Heavy Traffic" on the basis of "Daily Volume of Commercial Traffic." This assumes that, on the average, counts of commercial traffic will follow a fairly uniform pattern of percentages of trucks and busses of various weights with usually not over 10 to 15 per cent having wheel loads approaching maximum legal limits (9000 lb ±). It would be possible, of course, to have a truck count of, say, only 40 per day, but with all these units having near maximum wheel loads. In such case the volume of 40 per day might well be the equivalent of several hundred per day of the average commercial count The division of traffic into classes might better be based on some formula for evaluating the various wheel loads, but with the foregoing explanation it is believed that the commercial traffic volume basis is good enough for the purpose of this discussion as an approximate illustration of the importance of the traffic variable

The lower chart consists of a series of curves showing thicknesses in inches plotted against group index of subgrade Curves A, B, C and D show subbase thicknesses and combined thicknesses of surface, base and subbase as taken from the upper chart Curve E shows additional thicknesses of high quality granular base which may be substituted for lower quality selected material subbase and is plotted on the basis of substituting 2 in of such base for each 4 in of selected material. Curves F, G and H show the combined thicknesses of surface, normal base and additional base for different traffic volumes The introduction of curves E, F, G and H in lieu of curves A, B, C and D is intended to take care of the variable "(e)" included in the report as "The factor of safety justified by availability of satisfactory subbase materials." These comparative total thicknesses are based on the assumption (supported by some observations) that the additional thicknesses of high quality base would be about as effective in fact as the greater thicknesses of selected material subbase, if such selected materials were of the lowest quality permissible under above description. Of course, if the selected material were approximately equivalent to high quality base (which is often the case) then the use of curves B, C and D would result in much greater factor of safety in the design than would use of curves F, G and H, and this may be justified by the small additional cost involved.

This outline is intended to cover primarily the design of foundations for bituminous surfaces, but it is considered by the writer equally applicable to portland cement concrete surfaces which are to carry heavy volumes of truck traffic. The use of a thin layer of high-quality granular base supported by subbase as needed should often result in actual economy by permitting design of thinner slabs and by preventing some of the displacements at cracks and joints which so often occur under heavy traffic

While this outline is based on the use of only granular base and subbase materials for foundations, it is recognized that some materials not satisfactory as granular base can be made suitable as base by bituminous or cement treatment, particularly those materials described as "Good" and "Fair" Such treatments are sometimes economical as compared to importation of high-quality granular bases. Tests have been developed for determining whether such treatments of particular materials should provide satisfactory base courses, but these will not be discussed here.

This discussion has indicated that pavements should vary from only surface treatments of "Excellent" native subgrades for very light traffic to total thicknesses of as much as 18 to 24 in. of surface, base and subbase over "Very Poor" subgrades for very heavy volumes of truck traffic. It is not expected that there should be great difference of opinion on the desirability of these extreme variations in required thicknesses, on the bases of traffic volume and subgrade characteristics, as such variations are well established by actual practice in many localities. The difficult problem is, of course, the determination of rational designs for conditions between the extremes, and the purpose of this outline has been to suggest a solution to that problem. While the solution is necessarily imperfect for all the many possible variations of the problem, it is hoped that its investigation by others may result in the tying down of more points between the extremes, and it is believed that the outline is well adapted to incorporation of other subgrade test methods where desired, such as those listed in the report under "Supplementary Tests" and those that are certain to be developed as progress continues.

Attention is directed to the desirability of the factors of safety represented by the subbase or "additional base" thicknesses here recommended when considered from the viewpoint of long-range performance of the pavement. That these subbase and "additional" base thicknesses are actually factors of safety for reducing maintenance costs and prolonging the life of pavements can be demonstrated by observation of pavements constructed to about the thicknesses for various volumes of traffic as shown on the upper chart for surface and base only without regard to soil types or subbase treatment. Assuming that subgrades were initially well compacted, all these pavements will serve very well for the first few years Where subgrades are actually "Good" they will continue to give practically trouble-free service for many years, while where subgrades are inferior troubles will start after a few years and maintenance costs will mount, resulting eventually in necessity for pavement reconstruction before the roads are otherwise obsolete The outline of design here given is well adapted to sound "Stage Construction." Where limitation of funds may offer the temptation to reduce the factor of safety in initial pavement construction it is recommended that this should be taken out of the surface rather than the base or subbase elements. That is, the desirable thicknesses of granular base and subbase should be placed with a temporary thin surfacing, with the thicker designed surfacing to follow as soon as feasible. This type of stage construction is also desirable where physical conditions are such that embankments cannot be constructed initially in such manner as to prevent subsequent distortion.

In closing, it is desired to direct attention to two tendencies that often develop with the adoption of extensive investigation of subgrade materials by tests and the laudable desire to make the greatest possible use of local materials. One is the tendency to abandon all attempts at visual identification of the various soil types and rely entirely on the laboratory test results. There should be continuing effort to promote familiarity with the tests by all engineering personnel concerned and to teach such personnel to tie the test evaluation to visual observation This would be aided by development of more practical and expeditious field tests. The other tendency is that of attempting to substitute mere thickness for quality of materials. While many materials such as those identified as "Good" and "Fair" may be entirely satisfactory as subbase over inferior soils, they usually are not satisfactory for use as granular base as herein defined. The topping of a subbase with as little as 3 or 4 in. of base of unquestionable quality may mean the difference between success and failure of the pavement design. Also, it should be kept in mind that examples of failure caused by use of materials borderline in quality for base is not evidence that the same materials are not satisfactory as subbase. For instance, a 12-in layer of borderline base material over a poor subgrade might be an unsatisfactory foundation for a thin bituminous surfacing. Yet the use of 8 in. of this same material topped with 4 in. of high-quality base may be just as satisfactory as substituting an entire 12-in thickness of more expensive high-quality material