

Flexible-Pavement Design by the Group-Index Method

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● A METHOD of design, based mainly on group index and heavy traffic, has been used by the Missouri State Highway Department since 1947 to determine total thickness to recommend for flexible pavements.

Prior to that time the principal distinction between projects within the secondary system was established by the traffic count. The base of a lightly traveled road usually consisted of 4 to 6 inches of stabilized clay-aggregate mixture, while 6 inches of higher-type base material (such as waterbound macadam, soil cement, or bituminous stabilized material) was generally used on roads carrying heavier traffic. Interpretation of the exact meaning of lightly and heavily traveled roads was pretty much left up to the judgment of the designer. Little consideration was given to base thicknesses greater than 6 inches, because of a belief that subgrade soil so deficient in stability that it required more than 6 inches was too weak to support a flexible pavement. Therefore, in such cases, the routine course was to design for concrete.

Total thickness varied due to the practice of varying the bituminous wearing course, which might be an armor coat, double seal, oil mat, or asphaltic concrete.

Through the years following completion, these roads showed great differences in performance. Many functioned well until heavier type traffic and the unavoidable decrease in maintenance during the war years began to exact their toll.

The end of World War II marked the beginning of a change in our policy regarding soils information which, prior to that time, had been given to the designer without definite recommendations concerning its most-advantageous use. Since few designers were equipped with the specialized knowledge necessary to make full use of the information provided, there was some reluctance even to try

to use it. Fundamentally, design was based on past experience in Missouri.

The somewhat-gradual deterioration noted in many of our roads during the war years was speeded up by the marked post-war increase in traffic volume and weight. As a result, the spotlight was directed toward our rather casual attitude concerning the importance of base thickness, emphasizing the inadequacy of our design and indicating the need for the development and adoption of a definite design method. Additional stimulus was provided by the return of many engineers from war work, where they had assimilated ideas concerning the latest practices in design and construction of flexible pavements, as well as in the practical application of soils data obtained from field and laboratory investigations.

However, "the homecoming of the wise men" could hardly be called an unmixed blessing, inasmuch as discordant opinions were frequently held and strongly defended by designers, construction men, and soils engineers. The all-important straw was added to the camel's load in 1947 when the Soils Division specifically recommended an 8-inch base in an area where 6 inches was considered by the designer to be ample thickness.

This recommendation engendered much discussion but the base thickness was set up for 6 inches. Perhaps the most-important result of all the conversations was that one idea crystallized from many, when it was decided that some definite method of thickness design should be established for use by the Missouri State Highway Department.

It was realized that the group index was developed as a soil-classification tool, easily determined from simple soil tests performed by all laboratories. We were aware that bearing values, obtained in one or another of several ways, were used by numerous organizations to determine base

thickness, and that we might be among the minority if we chose to ignore the path followed by so many.

For several reasons, however, we elected to do just that, not the least of which, perhaps, was the show-me attitude of the Missourian. Nobody had convinced us that any one bearing test was better than any other, and our routine tests did not include those for either bearing value or shear. We felt that, since the group index involved no tests complex in themselves or in the diagnosis of their results,

The proposed chart was preferably to be uncomplicated and to utilize only such soil tests as were commonly made in our laboratory. Although at the time of origination it was considered to be only the first step in the right direction, the second step has not been taken and the chart in use today remains essentially the same as the original.

The chart was developed in the following manner:

1. CBR and Proctor density tests were made on all horizons of 32 typical soils of

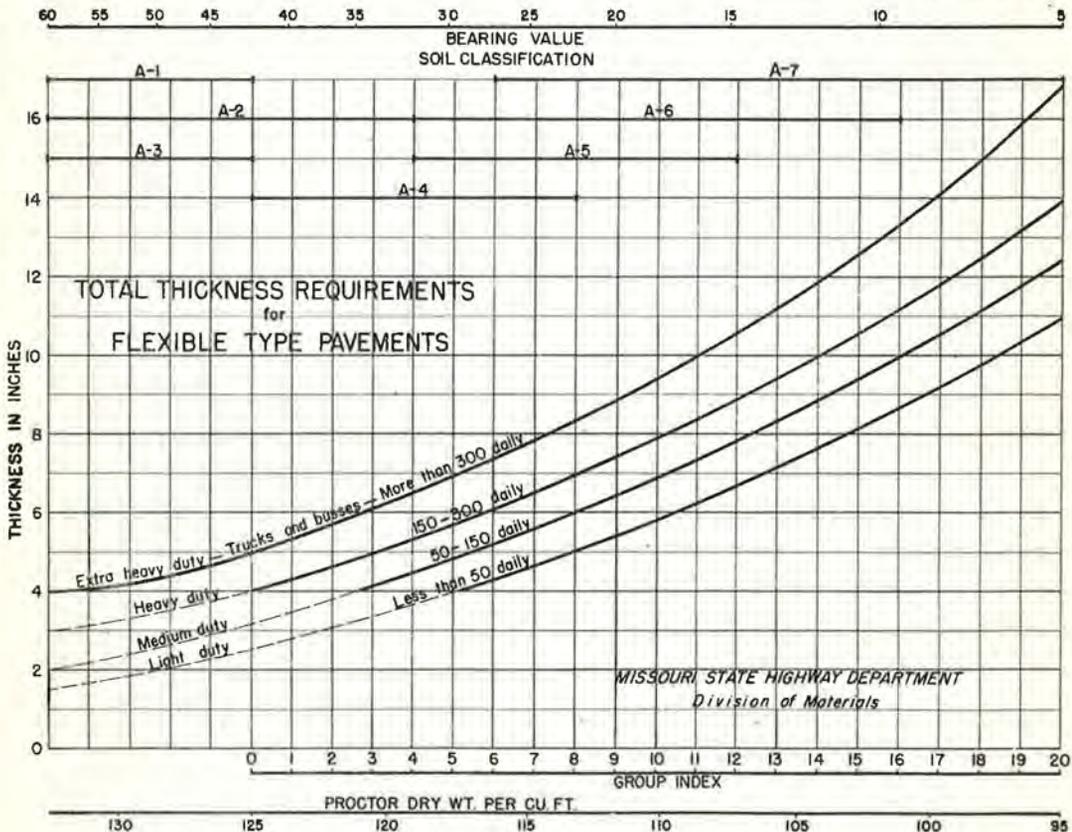


Figure 1.

it met our demands for simplicity and should serve satisfactorily as the basis for our design method.

Various ideas were advanced and different approaches tried before the final decision was reached that our thickness chart would be based primarily on the group index of the subgrade soil and the volume of heavy traffic (trucks and busses), with minor adjustments being influenced by the maximum dry weight of the soil.

Missouri, with the exception of most of the thin, organic A horizons.

2. CBR tests were correlated with bearing value as shown in sketch, SCX-16 assembled by the Portland Cement Association (1).

3. Use was made of Highway Design Charts H-10, H-15, and H-20, presented in an Asphalt Institute Progress Report (2) to determine the correlation between varying bearing values and total thicknesses of

base and asphalt surface. These values were slightly changed before plotting, with the extra-heavy-duty curve corresponding to the Asphalt Institute Curve H-20, heavy duty corresponding to H-15, and medium duty corresponding to H-10. The light-duty curve was added by extrapolation.

4. It was thought that repetition of critical loading was more important than wheel loads alone. With some changes, D. J. Steele's (3) designation of light, medium, and heavy traffic was applied. Our classification agreed with his in the light duty class (less than 50 commercial vehicles daily), but because a different set of conditions prevailed, we called his "heavy duty" extra-heavy duty, (300+) and broke down his "medium duty" into medium duty and heavy duty (50-150 and 150-300).

5. From the Portland Cement Association sketch the relationship between CBR, bearing value, and PRA (now BPR) classification was established. The BPR classification as shown in the sketch was, however, changed to be in line with the 1947 proposed revision (4).

6. Charting the revised BPR classification, which included maximum group index limits for each A group, automatically established the maximums on our thickness chart, while the minimums were fixed to conform to experience with Missouri soils.

The thickness chart is used by the Plans and Surveys Bureau, since it is that bureau's responsibility to set up all phases of the design, including thickness and width, type of base, and surfacing. However, furnishing reliable information concerning soils, excavation classification and drainage is one of the functions of the Division of Geology and Soils. The field representative of this branch of the department assumes the responsibility for obtaining the necessary information, interpreting soil test results and field conditions, and offering suggestions that will help the designer to derive greatest benefit from the available data. He finds use of the chart essential to complete fulfillment of these obligations.

On projects through new locations where grading work must be done, the district geologist or soils engineer makes borings to determine the presence of any ledge stone and to classify the different soil types according to the U. S. Department of Agriculture, Bureau of Soils, Method. Natural-density tests are made for estimating soil

shrinkage, and samples from each horizon of each soil type are submitted to our Jefferson City Laboratory for routine tests.

The geologist writes a soil-survey report, which includes a description and test data for each soil involved in grading operations or which will form subgrade for the base, notations about any unusual drainage conditions, shrinkage factors for use in computing earth balances, location of ledge stone if it occurs, and other geological features. This report, with the geologist's interpretation of all the pertinent information obtained from both laboratory and field work, is submitted to the designer.

On reconstructed routes where no grading is required, frequent and accurately measured soundings determine the salvable thickness of the old wearing course and base, and borings are made to determine the major soil changes in the subgrade. Typical samples of subgrade material are tested. Where base sufficient to be of value in stage construction is found, it is sampled and tested for P. I. and gradation. A report is then submitted to the designer describing the amount of salvable material and its probable value, the subgrade soils, and drainage conditions.

After evaluating the effects of the group index and the latest traffic count of heavy vehicles, the designer uses the thickness chart as a guide to determine the total thickness of base and surfacing. Consideration of a material survey report on available materials enables him to specify the type of base and surfacing to be used. Information contained in the soil-survey report helps him to specify the type and location of special drains, and such selective soil handling as may be necessary or desirable.

Application of the thickness chart usually involves only group index and heavy traffic; but in certain cases, as in the following example, consideration is given to the maximum dry weight. Assuming a group index of 10 and extra-heavy traffic (300+) the chart indicates the necessity of a total thickness of 9.5 inches. Whether to specify 9 inches or 10 inches is then influenced by the dry weight. Since the group index of 10 almost exactly coincides with 110 lb. per cu. ft., a weight greater than 110 would be considered to be a better soil and need less total thickness. Theoretically, then, 9

inches would be specified. Thus, a lower weight, poorer-type soil would demand a greater thickness, and 10 inches would ordinarily be specified.

Since its adoption, the chart has been used to design thicknesses for projects in various parts of the state which, because of the scattered locations, offer contrasting soil, climate, drainage, and traffic conditions. Detailed descriptions of the design, construction, and performance of some of the projects follow:

ROUTE SK, ANDREW COUNTY

This 5.25-mile project extends from Amazonia to the Buchanan County line at the edge of St. Joseph, in northwest Missouri. About a third of this project lies in the Missouri River flood-plain area adjacent to a prominent escarpment, while the remainder of the project is located in heavily rolling upland topography. This contract consisted of a few short sections of re-alignment, raising the grade in some of the bottomland area, and constructing a rolled-stone base with bituminous surface. Construction was started in April and completed in November, 1949.

During a soil survey in the spring of 1947, the limits of the soils were determined, and those that would comprise the subgrade for the new base were sampled and tested. The soils were identified as Knox and Marshall silt loams in the upland area, and Sarpy clay loam, Pennsylvanian shale, and glacial till in the low area adjoining the escarpment. Fifteen representative soil samples showed group indexes ranging from 2 to 11. Based on a medium-duty traffic count and these group indexes, the total thickness recommendations by the division geologist for the designer's guidance were 9 in. in the first 2,550 ft., 5 in., 7 in. or 9 in. in the next 8,700 ft. (depending on the source of borrow material for raising the grade), and 7 in. in the remaining 16,615 ft. The suggestion was made that French-type shoulder drains be installed through areas of the more-impervious subgrade.

A material survey, made in this locality in 1944, indicated no gravel available in the immediate area. Two limestone sources near the project were located and sampled, both deposits being identified as the Oread formation of Pennsylvanian age. Portions of the ledge were

accepted for use in the production of aggregate for bituminous surfacing and the entire sampled thickness was accepted for use as rolled stone base.

Changes in plans subsequent to the original soil survey necessitated variations in thickness from those recommended. The thickness of the 24-ft.-width base as constructed was 9 inches for the first 1,510 feet; 7 inches for 5,140 feet; 9 inches for 440 feet; 7 inches for 1,060 feet; 9 inches for 2,030 feet; and 7 inches for the remaining 17,685 feet, or a total of nearly 24,000 feet of 7-inch base and approximately 4,000 feet of 9-inch base. The 7-inch base was constructed in two lifts, and the 9-inch base in three equal lifts. The density specified was at least 95 percent of the standard Proctor maximum. The bituminous surface course was constructed to a width of 22 feet, and consisted of two applications of MC-5 with a total of about 45 lb. of aggregate per square yard.

The daily traffic count on this route in 1948 just before it was closed for new construction was 901 vehicles, of which approximately 150 were trucks and busses, thus making it a borderline case between medium and heavy duty. The medium-duty classification was used as a basis of design, even though past experience indicated that some increase in traffic is a logical expectation after improvement of a project. The 1952 traffic count on this project followed the usual pattern, increasing to 1,360 vehicles, of which about 240 were trucks and busses. This indicates that anticipated traffic should have been the basis of design, in which case the heavy-duty curve would apply and a greater base thickness would have been specified.

Maintenance costs for a 13-year period before reconstruction averaged \$355 per mile per year. Since reconstruction the maintenance costs have averaged \$249 per mile per year for the 3-year period, of which more than 92 percent was spent for cover material when the bituminous surface showed excessive bleeding shortly after construction was completed. Repairing small failures accounted for the remainder.

The condition of this route in October of 1953 was unsatisfactory. The first 1.7 miles of the project, which is on the flat grade through the bottom, and hence, in an area of poor drainage, showed somewhat

more severe distress than the remaining 3.55 miles located in the hills. Through the 1.7-mile section there were eight small failed areas totaling about 700 sq. ft. Several other areas showed severe cracking and distortion. Much longitudinal cracking and some corrugating was particularly noticeable in the outer wheel tracks. In the 3.55-mile section, there was one failure of approximately 300 sq. ft., a few other areas were severely cracked and distorted, and longitudinal cracks with slight accompanying depression appeared in most of the cuts and on the low sides of curves.

An attempt will be made to remedy the existing condition by resurfacing next spring with a plant mix of penetration asphalt and mineral aggregate sufficient to give an additional thickness of about 3.5 inches.

ROUTE 59, ATCHISON COUNTY

This north Missouri project extends from the Iowa line to Tarkio, a distance of 7.8 miles over lightly rolling topography through soils of loessial and glacial origin. The old road was oiled earth. New construction, between August 1949 and July 1950, included a few sections of light grading but primarily consisted of placing a rolled-stone base and bituminous surface on the oiled earth.

A soil survey made in December of 1948 showed that the subgrade generally consisted of one of the three horizons of the Marshall silt loam, a loessial soil, although in some areas a glacial soil (Shelby silt loam) was found. Five representative soil samples were tested, three showing a group index of 8 and two of 11. Based on a medium-duty traffic count and the group indexes, the chart indicated that thicknesses should be 6 and 7.3 inches, so a total thickness of 7 inches was recommended throughout the project. No special drainage was recommended.

Material surveys several years previous to 1949 had indicated no stone deposits of any consequence in the county and only small scattered deposits of poor quality glacial sand and gravel. Therefore, crushed stone was shipped from the most-economic source, a distance of approximately 65 miles.

A rolled-stone base 6 inches thick and 22 feet wide was constructed throughout

the project. The lower of two lifts was 4 inches thick, the upper was 2 inches and the specified compaction for each was at least 95 percent of Proctor maximum density. The base was topped with a double bituminous surface treatment 20 feet wide, in which the total aggregate used amounted to about 60 lb. per sq. yd.

The average daily traffic count in 1949 before construction started was 493 vehicles, of which approximately 69 were trucks and busses, placing it near the lower limit of our medium-duty classification (50-150). In 1952, 2 years after completion of the project, the traffic showed a very slight increase to 526 vehicles, of which about 73 were trucks and busses.

The maintenance costs for 13 years previous to reconstruction averaged \$470 per mile per year. Since reconstruction the annual per mile surface maintenance costs have averaged \$152. Maintenance has consisted of repairing a few failures and spot sealing surface blemishes.

A condition survey of the project in October 1953 showed one large failure of about 500 sq. ft. and three other failures totaling 50 sq. ft. Another 2,000 sq. ft. has shoved and corrugated, and longitudinal cracks are almost continuous throughout the project in the outer wheel lanes.

Improvement similar to that for the previously described route is scheduled for this project in 1954, when approximately a 3.5-inch-plant-mix will be placed.

ROUTE STT, ST. LOUIS COUNTY

This project is a 4,600-foot relocation in the northern part of St. Louis County, in east central Missouri, through rather level terrain along a terrace or second bottom of Coldwater Creek. Grading of the new location started in August of 1951, and the construction of a rolled-stone base surfaced with asphaltic concrete was completed in October, 1952.

From the soil survey made in December of 1949, it was determined that the project was located in an area of reworked loessial soils. These soils were identified as Bremer silt loam, a soil containing a large amount of silt and organic matter, and Robertsville silt loam of similar texture but containing much-less organic

material. Samples representative of the horizons of each soil type were tested. Results showed almost identical group indexes of 8, 10, and 13 for the A, B, C horizons of the Bremer and 8, 10, and 14 for the Robertsville.

An effort to anticipate the worst condition influenced the division geologist to suggest in his soil-survey report that the group index of 14 be used as the criterion for determining the pavement thickness. Based on this group index and an anticipated extra-heavy traffic count, the recommendation was made that 12 inches of total thickness be used throughout the project. Special drainage installations were not necessary, and the materials problem was simplified because several established quarries operated nearby.

The recommendations for this project were followed without variation. A total pavement thickness of 12 inches was constructed, consisting of a 9-inch rolled-stone base, 26 feet wide, and a 3-inch asphaltic-concrete surface, 24 feet wide. The base was compacted in three equal courses, each to at least 95 percent of Proctor maximum density.

The daily traffic count on this project in 1950 was 761, of which about 33 were trucks and busses. Relatively little traffic used the route before improvement, because of the narrow, hazardous roadway. Recent data is not available, but observation indicates that the increase has been considerable.

The condition of this road at present is excellent and there have been no maintenance costs.

ROUTE 21 TR, JEFFERSON COUNTY

This project is a relocation of a portion of Route 21 bypassing the City of DeSoto. The 6.84-mile project traverses hilly topography of the Ozark region, where deep cuts and high fills involved excavating and handling large quantities of both ledge stone and dirt. Grading started in June of 1947, and the pavement, consisting of rolled-stone base with a bituminous seal, was completed in July of 1948.

The original soil survey for this route was made in 1940, when the soil type throughout the project was identified as Union silt loam, a soil which is usually composed of fine-grained material of loessial origin overlying cherty, granular,

residual material. Group indexes of samples taken at this time varied from 10 to 14.

The project was designed in 1946, which was previous to the development of our thickness chart. The designer, with little information to guide him, set up the project for a 6-inch base with a bituminous seal. Excavation by the grading contractor exposed such extensive, heavy clay subgrade that construction personnel questioned the adequacy of the design and requested that a new soil survey be made.

The resurvey in 1947 showed nearly all fills to be capped with clay and the subgrade through most cuts to consist of shattered dolomite. Eight soil samples, considered to be representative of clayey sections throughout the project, showed group indexes ranging from 11 to 16. These figures, considered in conjunction with anticipated traffic in the medium-duty classification, indicated the necessary total thickness to be from about 7.5 inches to 10 inches. A supplemental report was submitted recommending a 9-inch base, which would be slightly increased by addition of the bituminous seal and probably fall just a trifle shy of the maximum thickness indicated by the chart to be necessary through the worst sections. A minimum of 4 inches of base material was recommended in the rock cut sections.

Adoption of these recommendations meant that the project had to be divided into clayey and stony subgrade sections varying in length from 550 feet to 3,040 feet and involving 19 changes of base thickness. The only special drainage installation was made to intercept intermittent seepage from a wet weather spring in the subgrade.

A material survey in the locality showed an abundance of Jefferson City dolomite of Ordovician age which was suitable for use as base material. Stone suitable for bituminous surface could be produced by selective quarrying of certain ledges. Local gravel deposits were insufficient in size to supply the necessary quantity of base material. Sufficient gravel of suitable quality for use as bituminous surface material was available in nearby stream deposits.

With but few exceptions, a 9-inch rolled-stone base was constructed in the locations recommended. A 6-inch base was built in all stony subgrade sections

instead of 4 inches as suggested. The base throughout the job was constructed in 3-inch layers, each of which was compacted to at least 95 percent of Proctor maximum density prior to placement of the next course. The base was full uniform thickness for 20 feet and feathered out on 8-ft. shoulders. Prime was applied to the full 36 feet, and a bituminous surface consisting of 75 pounds of stone chips per sq. yd. was placed on the 20-foot width.

Since this project is on new location, traffic comparisons before and after are not possible. The first available traffic count was in 1952, which showed a daily average of 1,133 vehicles (about 240 trucks and busses). In 1953 this traffic had increased to 1,246 vehicles, of which 262 were of heavy classification. Both of these counts are well up into the heavy-duty class instead of the medium-duty for which the project was designed.

The exact maintenance costs on this 6.84-mile section are unavailable. Prorating the 4-year costs of a maintenance section which includes this project and an adjoining 5.5-mile section of similar construction gives an average of \$129 per mile per year.

Within a year after completion of this project two areas failed. Both were on fills and grades, and both occurred where the base thickness was 6 inches. The smaller (160 sq. ft.) showed a marked stratification in the subgrade material with several inches of silty topsoil overlying tight clay. The capping layer picked up moisture which could not escape and developed a condition which resulted in failure. The larger failure (2,250 sq. ft.) occurred on clay subgrade and was probably caused by one of the few unaccountable variations from the recommended procedure. A 9-inch base on this section would undoubtedly have reduced the probability of failure. The same statement might be made concerning the smaller failed area, but better construction procedure would have spread the topsoil on ditch inslopes or mixed it with the clay, rather than concentrate it in a layer capping an impervious clayey soil.

Accurate observations of this pavement have been infrequent since 1949, but conversations with maintenance patrolmen indicate that no further failures have occurred. Minor surface blemishes have developed in the traveled way and raveling

is conspicuous on the primed shoulders.

In 1952, this project was resurfaced with 3 inches of asphaltic concrete for a width of 22 feet as a protective surface coating, rather than as insurance against the development of base failures. No surface maintenance has been charged against the job since that time and the road is in excellent condition.

ROUTE 62, NEW MADRID COUNTY

This project extends from Risco to Malden, an almost perfectly flat distance of 8.2 miles across part of an old Mississippi River flood plain near the Bootheel section of southeast Missouri.

The 20-foot pavement, previous to improvement, consisted of concrete slabs, some of which were 9 feet and some 10 feet wide. The remaining 10 or 11 feet consisted of either bituminous surfaced thin gravel or oiled-sand base.

Although the concrete slabs were performing satisfactorily, the bituminous widening presented a constant and expensive maintenance problem. Through the years various methods of treatment were used in an attempt to improve this road. It was felt that some salvage value was recoverable from the existing roadway so the design was set up to make full use of such material as was available.

A condition survey made in February of 1948 to determine the quantity and quality of salvable material showed wide variations in base material. Fairly clean and rather dirty sand was found, as were oil-sand mixtures, clayey gravel, and clean gravel in amounts that were not at all consistent but were revealing as to the attempts to build stability into the job in past years. Estimates were made of the amount of recoverable material in the various sections.

The alluvial subgrade soils were identified as Sharkey and Waverly types, varying from organic clay loams to sandy loams. The group indexes of the eight samples tested varied from 0 to 12.

With the expectation that the road would be subjected to traffic corresponding to our extra-heavy classification, recommendations were made for total thicknesses varying from 6 to 11 inches as the quality of the subgrade soil varied. Twelve changes in thickness were involved in sections of lengths varying from 530 feet to 10,725 feet. The report also contained a recom-

mentation that water be removed from the base by drains through the shoulders, even though dissipation of water collected by ditches in this area is usually accomplished by the slow process of evaporation. Normal conditions in this level section of Missouri usually mean high humidity and high water table, neither of which are conducive to rapid elimination of surface water.

Material deposits are scarce in this section of Missouri, being confined primarily to rounded chert and quartz gravel and sand deposits containing varying amounts of binder and occurring in a long hill known as Crowley's Ridge. Suitable deposits within this ridge had been previously located at a distance of 7 or 8 miles from the project.

Construction of this job was completed between August 24 and November 25, 1948. With the exception of 9,000 feet of 6-inch base near the middle of the section, the base thickness throughout was 8 inches. Base material was produced by two methods: The lower portion consists of a mixture of broken, salvaged, bituminous material and any underlying base of whatever nature, while the top course was stabilized gravel in sufficient quantity to produce the specified thickness.

Because the gravel in its natural state contained too little fine material and showed too high plasticity to meet our specification, fine sand (also a Crowley Ridge deposit) was hauled to the project and windrowed in quantity such as to bring the total material within specification limits on both counts. The sand, gravel, and moisture for compaction were mixed in one operation by means of a traveling mixer. Minimum compaction was specified as 95 percent of Proctor maximum density. The base was placed in a trench 11 or 12 feet wide, as determined by the slab width, and was surfaced with an open-type, coarse-graded, asphaltic concrete, 2 inches thick and 1 foot narrower than the underlying base. Recommendations were ignored and no drainage of any type was provided.

The contractor was working against time and time was fast running out on him, as it often does for anyone proposing to place asphaltic concrete during November in Missouri. Unfortunately, several rains fell while long sections of trench were lying open. Removing ex-

cess moisture from wet subgrade by aerating and discing is a fine idea in certain circumstances; but in damp, cool, cloudy weather over a southeast Missouri flat, undrained, trench section it was a lot of waste motion. A few soft and unstable spots were removed, but many were not, and the base was apparently mudded-in in quite a few areas.

The failure of this road might be, for the most part, ascribed to the fact that construction was hurried because the season was so late. In order to reduce the probability of a winter shutdown on an unfinished job, good construction practice was disregarded and the effects soon became evident.

The daily traffic count in 1947, a year before reconstruction of this route, was 1,146, of which about 225 were trucks and busses. By 1953 these figures had increased to 1,369 vehicles, of which 280 are of the heavy type. Into this category fall many trucks often thought and sometimes proved to be loaded considerably in excess of the legal maximum of 18,000 lb. per axle. Watermelons, soybeans, and cottonseed are produced in large quantities, and in the fall huge loads are often hauled over roads inadequately designed to withstand such weight.

The average annual surface maintenance cost of this section for an 11-year period prior to reconstruction was \$360 per mile. Since reconstruction (1949 through 1952) the cost has averaged \$392 per mile per year. These figures include the costs for resealing the entire section and repairing broken and failed areas.

As indicated by these figures and confirmed by visual observation, the reconstruction of this road was not successful. About 75 small, scattered failures totaling approximately 100 sq. yd. developed and were repaired by the contractor before he left the job. Failures subsequently grew in number and size and other defects appeared, until by the following summer (1949) 7 percent of the total area of new construction showed complete failure, 8 percent was severely depressed or near failure, 6 percent was slightly depressed, and 33 percent had been resealed to cover the cracks. Most of the distressed areas occurred in the western 2 miles, which were the latest constructed, and nearly all failures were observed in areas over the poorer subgrade soils.

Serious deterioration shortly thereafter came to almost a complete standstill, with new failures developing nowhere except within the 2-mile section, where the occurrence of new defects proceeded at a much slower pace. At present this pavement is performing satisfactorily, except for the western 2 miles which, although rough, is still serviceable. No additional construction is planned for this project at the present time.

IMPROVEMENT OF SECONDARY ROADS

Many secondary roads in Missouri have been built up over a period of years, primarily as a result of routine maintenance. Periodic addition of replacement material, ditch pulling, maintenance, stabilization and maintenance oil mats, decks, seal coats, etc., are all instrumental in building thickness, stability, and some value into such roads. In conjunction with a thickness survey, our chart has been used as a guide when some of these roads have been scheduled for further improvement, as well as on projects too short to be included in this report. Missouri has recently done a great deal of widening and resurfacing of old, narrow and defective concrete pavement, where the chart has been used in determining the thickness of the widened portion on many of these projects.

Other instances of its use, none of which have any place in this report, may be cited as on projects originally set up for flexible pavements but on which the final design was for concrete. There are also a few projects in various stages prior to letting of the contract, on which chart recommendations have been reported and which may or may not reach the construction stage as flexible pavements.

Since its introduction as a tool for design, unforeseen obstacles have sometimes barred the way to as complete use of the chart as was expected, and it has, in some cases, been used improperly or not at all, experiences which are probably not peculiar solely to Missouri.

We feel that we have accumulated insufficient data to permit an accurate evaluation of our method of design at the present time. However we cannot fail to recognize the fact that it falls short of perfection, if there is such a thing in flexible-pavement design. We in Missouri

have just about abandoned hope of providing a design method that will solve all problems in all conditions and revolutionize the controversial subject of flexible-pavement-thickness design. If we can develop one that works satisfactorily in Missouri for Missouri conditions, we will consider that we have reached one of our important objectives.

Factors in Method Improvement

We believe that the accumulation of more data, both on completed projects and those yet to be constructed, will bring into sharper focus the shortcomings of our design method which we hope to improve by incorporating the knowledge derived from the study of several phases of the general road building program, in which we expect to emphasize the importance of the following factors:

Anticipated Traffic

More-accurate forecasts of the traffic to be expected in the future would permit greater accuracy in our thickness recommendations. The possibility of under-designing and thereby repeating the experience illustrated by Route K, Andrew County, and Route 21, Jefferson County, would be greatly reduced. As described previously, these roads were designed for medium-duty traffic, but improvement attracted traffic in such amount that they are well within our heavy-duty classification.

Overdesign of thickness in anticipation of traffic volume that never materializes is not good design practice, but might be justified by a saving in maintenance costs greater than the cost of the additional material.

Type of Base and Surface Course

Our method does not take into consideration the difference in bearing value between the various types of bases and bituminous surfaces. Crushed stone, keyed together by its angularity and lightly bound by the slight cementing action of its dust, probably has greater stability than a well-graded, rounded gravel containing soil binder. We know there is a difference in bearing strength between lime, soil-cement, stone, and mechanically stabilized

bases, but our design does not take this into consideration.

Frost and Drainage

It is about 300 miles from the Iowa line at the north to the southeastern tip of the Bootheel in Missouri, which is only 70 miles from the Mississippi state line. Average frost penetration varies from about 20 inches in north Missouri to about 5 inches in the Bootheel. The detrimental effect of frost on pavements in Missouri is not great but may be sufficient to warrant consideration in any revision of our method of design.

Good design procedure must necessarily provide for removal of water which collects in a base. If drains are not installed, additional thickness might help to compensate for the lack. In our design we make no allowance for additional thickness if the drainage is poor.

Construction

Latent though fundamental assumptions underlying our method of design are: (1) construction materials meet our specifications; (2) field testing and inspection for gradation, plasticity, moisture, density, etc., is accurate and test results are reliable; and (3) construction methods comply with those accepted as standard practice.

When one or more of those assumptions proves to be not well founded and failures appear in the road, we hope that further experience will provide the knowledge that will enable us to pinpoint the causes of trouble.

Proposed Group-Index Revision

We have done some work and intend to do more toward revising the method of determining the group index. We propose an approach to the problem which will enable us to reduce the amount of testing necessary, basing the determination on P. I. and plastic limit. Perhaps adaptation of the agronomists' field capacity and wilting point, in terms of P. I. and plastic limit, will enable us to determine the group-index limits from a different viewpoint than at present. We believe there should be some method of taking into account the decreasing stability inherent in a

soil while its moisture content ascends the plastic range.

The members of the Soils Division of the Missouri Highway Department recognize at least some of the inadequacies of our present method. Since the failures occurring on some of the projects designed by our method can easily be accounted for by factors other than erroneous soils information, we have had no particular reason to consider re-examination, evaluation, and revision of our design method. When that point is reached, we believe that complex tests will not necessarily provide the complete answer to our problems.

A systematic study of conditions before, during, and after construction and accurate, periodic observations of the performance of various type flexible pavements, in soil and climatic conditions as found in Missouri would, we believe, more nearly provide the information we now lack for making an intelligent revision of our design method. Such a program has not been inaugurated in Missouri, but we have hopes of starting such a study in the near future.

Additional impetus has been given to a review of our method of design by a recent directive to the effect that, on secondary roads in the Missouri system, a minimum 8-inch base and minimum 1½ inches of bituminous surface will be constructed, unless a lesser thickness is justified by the soil survey. Since this provision, if always adhered to, would eliminate from consideration approximately 70 percent of our chart, a critical analysis of the many and various methods of design becomes the first order of business in Missouri. An effort is being made to determine whether something better than our present method can be developed, retaining if possible the simplicity which we feel is one of the desirable characteristics in the group-index method of design.

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