good that resealing or maintenance has not been necessary.

Although relative roughness comparisons of the pavement's surface were not made instrumentally at the end of five years, the riding quality of the sections containing both the submerged and surface type weakened-plane joints has continued to remain very satisfactory. This characteristic belies the surface appearance of the cracks that formed over the submerged parting strips.

SUMMARY

In this report the performance of the experimental sections has been traced through five years.

It has been shown that: (1) changes in pavement elevation have been small and there is nothing to indicate that these changes have affected the relationships established in this report; (2) excepting the very short sections, daily and annual changes in section length are not directly proportional to length of section; (3) the magnitude of the restraint offered by the subgrade is a function of the time in which a given temperature or moisture change occurs in the pavement; (4) maximum tensile stresses originating from subgrade restraint develop in the late summer and fall; (5) frequency of cracking increases with increase in section length; (6) surface appearance of cracks is a function of width and crack width decreases with increase in amount of longitudinal steel; (7) all of the cracks have remained so tightly closed that they have little if any structural significance.

RIGID TYPE PAVEMENT JOINTS AND JOINT SPACING

By H. F. Clemmer, *Engineer of Materials, District of Columbia*

SYNOPSIS

The Highway Department of the District of Columbia has investigated the movement of concrete pavements and ascertained it to approximate that generally assumed in theoretical design. It has been found that the shrinkage of the concrete in setting will provide sufficient expansion space for pavements constructed during normal summer conditions, and that if planes of weakness are constructed at approximately 15 ft intervals a certain degree of dowelling across the joints will be maintained

Experiment and experience over ten years have proved that the division of concrete bases into slabs 12½ ft. long will provide definite control of cracking in sheet asphalt surfaces; the movement at any one joint being so slight as to be absorbed by the resilience of the bituminous surface.

The Highway Department of the District of Columbia recommends the construction of reasonably short slabs, and when available the use of well distributed reinforcement, tie bars at all construction joints and load transfers across all transverse expansion and contraction joints.

The rigid wartime curtailment in the use of critical materials, particularly steel, has required engineers to give particular consideration to design and construction methods to insure satisfactory and durable pavements when constructed with unrestricted materials Not only has it been necessary to design and construct pavements without mesh or bar mat reinforcement, but it has been necessary to design the joints without load transfers or tie bars. This has made the use and construction of joints in concrete pavements and concrete pavement bases one of the most important of the design problems The study given this problem and reports of experiments and field surveys have brought out many facts applicable to the use of joints for postwar design when steel and other critical materials will again be available

Concrete changes in volume with changes

in temperature and moisture, and to such an extent that consideration must be given to this phenomenon in the design of rigid type pavements and bases. Otherwise stresses may be created which will cause failures of the slabs During setting of cement, shrinkage of the concrete occurs and the slab as a whole tends to move on the subgrade. This movement is resisted by the force of friction which may exceed the low tensile strength of the green concrete, especially if not reinforced, unless the pavement has been divided at frequent intervals so as to reduce the mass of concrete. The higher the tensile strength of the concrete developed up to this time and the shorter the sections or slabs, the less frequent will be the cracks An important measure to assist in controlling and reducing the amount of shrinkage is to keep the concrete thoroughly saturated from the time of the initial setting of the cement The first action caused by the setting and hardening of concrete is heat development and general expansion of the mass It is important to retain the moisture in the concrete at this time, but it is even more important to supply sufficient moisture to the concrete at the time the temperature starts to decline, at which time shrinkage of the concrete starts If the concrete is kept thoroughly saturated during this period, the expansion due to the increased moisture will tend to offset the shrinkage caused by hydration of the cement.

Shrinkage during hardening, lowering of temperature, or drying of the concrete may create stresses greater than the tensile strength of the concrete which will cause irregular transverse cracks, thus producing free edges that must be considered in the endeavor to design uniform supporting slabs. Expansion of the concrete due to high temperatures or excess moisture, if confined, may create stresses in excess of the compressive strength of the concrete and cause failures such as "blowups" Research has shown that repeated application of load on concrete beyond a certain elastic or "endurance" limit (approximately 50 per cent of the maximum strength) causes fatigue of the concrete, and it is probable that a far greater area of pavement concrete, may be overstressed than would be replaced at the "blowup" section This conclusion is confirmed by surveys which show that the number of "blowups" are progressive with the age of the pavement Such a condition may have a permanent detrimental effect on the durability or life of the entire pavement slab and the repair of the particular section which has directly failed would not necessarily place the entire concrete slab in its original condition The continued changes in stresses in a confined pavement slab due to temperature and moisture variations together with loads applied by traffic may easily exceed the "endurance" limit of the concrete thus causing permanent deterioration of its strength and durability It is ordinarily recognized that general and progressive failures of pavement slabs start four or five years after placement of the concrete. It is thought that this fact may be due to fatigue occasioned by repeated stresses exceeding the endurance limit of the concrete.

Any joint in a slab, whether deliberately made or resulting from subsequent cracking, interrupts continuity of the concrete and accordingly constitutes a fundamental weakness unless provision has been made whereby each edge will function structurally with the adjoining slab in such a way that both edges, instead of one, sustain the applied load.

The strengthening of such edges by "load transfer" consists essentially in providing effective means for mechanical inter-action between adjoining slabs, whereby the two slab edges forming a joint will deflect simultaneously, rather than independently, under the action of a load applied on one edge only. The use of load transfers is of value in providing uniform surface elevation on both sides of the joint at all times Without such provision, a load in traveling across a joint, regardless of edge strength, will necessarily deflect one edge before it reaches the other—a condition which tends to aggravate impact on the joint edge Expansion due to the increased temperature during summer months may close free joints thus, in effect, dowelling the joints and so reducing this hazard, but it is necessary to make some provision for strengthening these unprotected edges, when conditions are such as to cause contraction of the concrete and therefore opening of the joints so as to present free edges of the slab.

It has been suggested that keeping the slab under compression at stresses well below the endurance limit (50 per cent maximum strength) would not only keep the joints closed so as to offset to some extent the lack of dowels or load transfers, but would tend to increase the resistance to flexural stresses caused by application of traffic loads. However, it is not believed feasible or practicable to so design and construct a concrete pavement slab that the concrete will be under compression throughout the entire year. The variations in temperature, the temperature at the time of placing the concrete, the distance between transverse joints, the subgrade conditions which affect changes in moisture, and the variables in the concrete as effected by the cement, are all that are difficult to estimate and control for the purposes of such design.

It is believed more practical, when necessary materials are available, to design pavement slabs of such dimensions that they are practically free to move when variations in moisture or temperature cause volume changes of the concrete. This provides definite conditions for which to design

The temperature at the time of placing the concrete and the maximum and minimum which may be reached are of first importance in determining the extent of volume change The length of slab to a considerable extent depends upon whether or not reinforcing (and, if used, what weight) is available. If reinforcing is not available, it is important to limit the length of slab to that length which will insure against cracking. The District of Columbia Highway Department has adopted a slab length of 15 ft. for non-reinforced concrete pavement. Volume change studies for concrete have established that the normal hydration or hardening shrinkage of concrete is approximately 0.02 per cent On a 15-ft. section this value for shrinkage would give a calculated hardening shrinkage of 0 036 inches Shrinkage of this magnitude when considered with a coefficient of expansion and contraction for concrete of 0 0000055 per degree F. is equivalent to that resulting from a 35 deg. F. drop in temperature Therefore, the shrinkage of concrete during hardening permitted by the installation of planes of weakness spaced at 15-ft. intervals, provides for a possible expansion without stress development of the concrete for a temperature change of at least 35 F. If concrete is placed at 70 F. (general summer conditions) it is apparent there is no need for further provision for expansion; nor is any further provision necessary for concrete having contraction joints spaced as close as 15 ft, when concrete is placed at temperatures as low as 50 F Considering a possible maximum temperature of concrete of 120 F, there would be a total range of but 70 deg, for which the expansion that may occur due to a change of 35 deg. is provided for, by the amount of shrinkage during hydration or hardening of the concrete, and the amount of compressive stress set up by the remaining 35-deg. change would probably be well within the endurance limit for pavement concrete As discussed previously, it is desirable to maintain pavement concrete under low compression as it tends toward dowelling of the joints and, increases resistance to flexural stress.

The Highway Department of the District of Columbia has constructed several concrete pavement projects following this theory,

Figure 1. Concrete Pavement Showing Planes of Weakness Spaced at 15 Foot Intervals

with planes of weakness spaced at 15 ft., using no expansion joints, no dowel bars across joints, no tie bars, and no reinforcement (Figure 1).

These projects approximating 160,000 sq. yd. of pavement were constructed in the spring of 1942 and at temperatures well above 50 F. It was thought that due to conditions pertaining in a municipality, that is, intersections with other streets, and with many utility structures in contact with the pavement non-uniform stresses might be developed and some "blowups" occur, but that the design would tend to insure maximum shear value across all joints. No such failures, however, have occurred up to this time (Dec. 1943). In this design which depends upon close spacing of transverse joints, it is important to insure the proper construction of these joints. Previous experience has indicated the need of cutting the concrete for at least one-half of its depth to be sure of creating the plane of weakness (Figures 2 and 3). It is, of course, desirable to divide the concrete, only enough to cause cracking, so as to obtain maximum shear value from the irregular

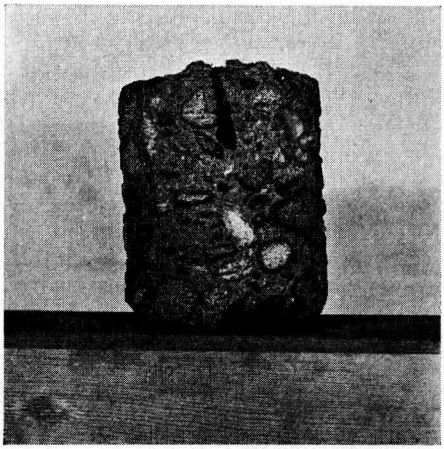

Figure 2. Paper Not Inserted Deep Enough to Create Plane of Weakness

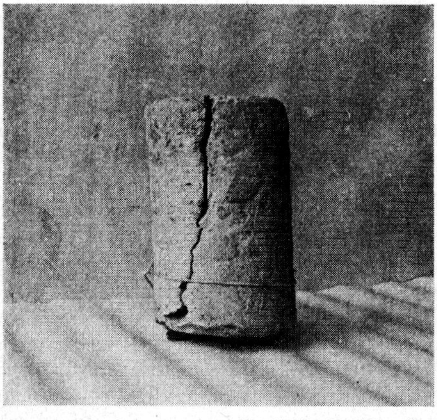

Figure 3. Paper Inserted Half the Depth of Slab Creating Complete Break of Concrete

edges and to provide maximum area in contact should the pavement be subjected to a high compressive stress. The department has found it necessary to cut the concrete at least to one-half its depth to be definitely sure of producing the transverse plane of weakness.

In an effort to determine whether the shrinkage of the concrete during setting of the cement approximated, under field conditions, that considered in the design; (.02 per cent) and to determine the movement of the concrete as indicated by readings taken across

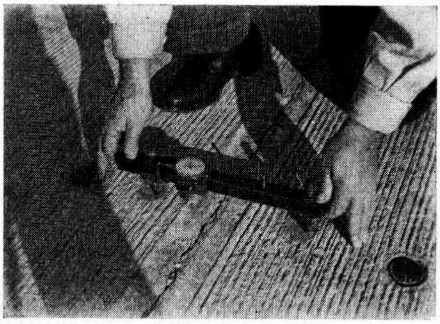

Figure 4. Shows Method of Taking Readings Across Joints

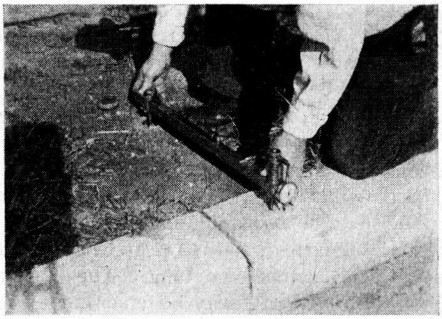

Figure 5. Shows Method of Determining Curling of Pavement Slab

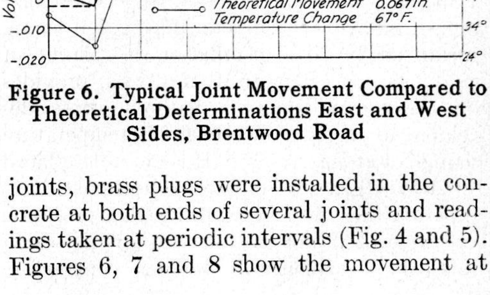

Figure 6. Typical Joint Movement Compared to Theoretical Determinations East and West Sides, Brentwood Road

joints, brass plugs were installed in the concrete at both ends of several joints and readings taken at periodic intervals (Fig. 4 and 5). Figures 6, 7 and 8 show the movement at these particular joints as compared to the theoretical determinations upon which the design was based. For the section of 15 ft and a coefficient of movement of 0.0000055, with integral curbs which undoubtedly reduced the general curling at these edges

A further check of the movement of pavement concrete was had by reference to a re-

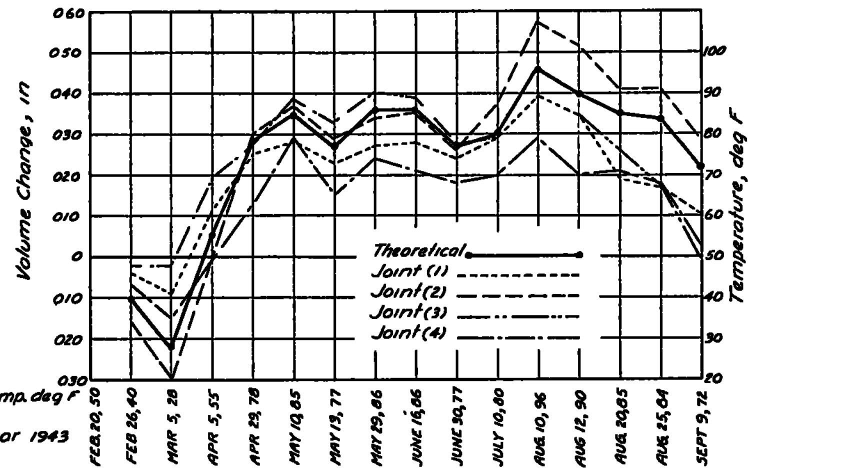

Figure 7. Movement of Four Joints on One Project Compared with Theoretical Determinations, Warren Street

disregarding subgrade friction stress, the theoretical movement would be 0 001 in. per deg change in temperature. As stated, the shrinkage which occurs during the hardening of the concrete for this pavement design approximates 0 036 in, that is, each joint would be opened to this extent at the temperature at which the concrete was placed. It is most interesting to note that the actual movement very nearly approximated the theoretical. These projects were constructed during summer weather conditions, that is, with temperatures approximating 70 F. The data indicate that the 0 036-in. per 15 ft allowance for expansion was sufficient without subjecting the concrete to compression—at least only to very minor compression And during contraction caused by low temperatures these joints have not opened more than 0 075 in., which would no doubt insure some transfer of load and probably enough to provide adequate protection.

Measurements were also made to determine the warping or curling action at the free corners of slabs. The greatest maximum noted was 0.06 in. which was not considered sufficient to require correction of the readings taken across joints. These pavements were built

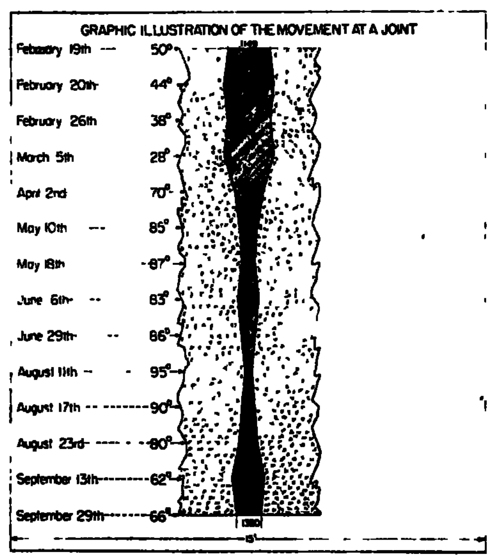

Figure 8. Graphic Illustration of Movements of a Typical Joint

search project conducted some time ago by the Department in which determinations were made of the volume changes of pavement slabs placed on a clay subgrade as compared to volume changes of "free" slabs of the same concrete. Plugs were set in pairs across each joint 5 in. from the edge of the slab for approximately 2,000 ft. along the roadway. Further plugs were installed in special slabs at approximately 10 in. apart and for the length of the slab and placed transversely as well as along the edge (Fig. 9). The pavement design included expansion joints spaced 90 ft. apart with contraction joints at 30-ft.

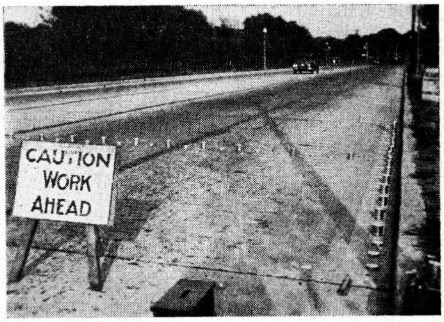

Figure 9. Plugs From Which Readings Were Made to Determine Movement of Pavement Slab

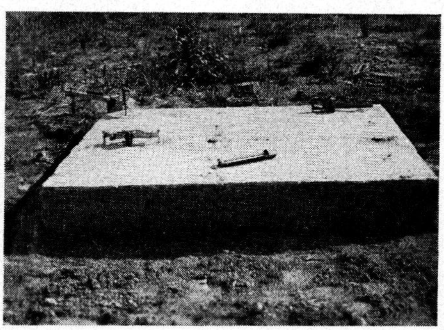

Figure 10. Free Slab and Placement of Strain Gauges for Determination of Movement of Slab

intervals. Reference slabs (approximately 4 by 5 ft. in area and of the depth of the slab) were constructed on greased steel plates in an endeavor to eliminate subgrade friction. These slabs were made of the same quality concrete and placed on the shoulders adjoining the pavement. Strain gages were clamped to these slabs and readings taken at regular intervals to note the varying volume change (Fig. 10).

It may be noted that the movement of the free slabs as shown on Fig. 11 is 0.00025 in. per inch for a temperature change of 40 F. Comparing this movement with readings on a pavement slab for 12 hours and a temperature range of 33 F., (Fig. 12) the movement for 40 deg. would be 0.000218, or a difference in the coefficient for volume change of from 0.0000055 to 0.00000625. This indicates that a coefficient of 0.000006 would be reasonable for this concrete. The movement of the pavement slab measured across joints (Fig. 13) as compared to the theoretical, which as

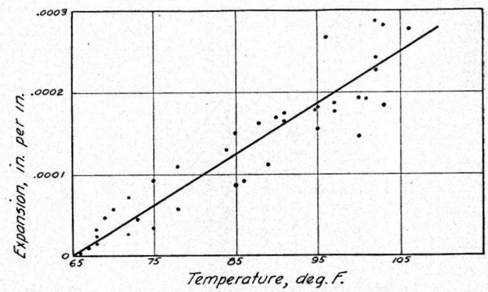

Figure 11. Average Movement of Free Slab, Due to Temperature Change, as Measured with Olsen Strain Guage

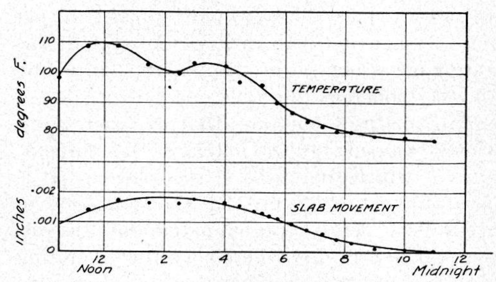

Figure 12. Movement of Pavement Slab

stated above is very close to the movement determined for the "free" slabs, indicate there is some lag at the lower temperatures, up to about 50 F. when there is a definite break in the slope of the curve and the amount of volume change for the higher temperatures approximately equals that of the free slab or the theoretical determination.

The possible "growth" of the concrete over a period of years and neglect of maintenance permitting inert material to fill the contraction joints will undoubtedly result in the pavement being subjected to some compressive stress but these stresses may not exceed the endurance limit of the concrete. It is believed the experimental data prove the logic of using closely spaced contraction joints, without any expansion joints when concrete is placed at normal operating temperatures for concrete pavements that must be constructed without steel as during this emergency.

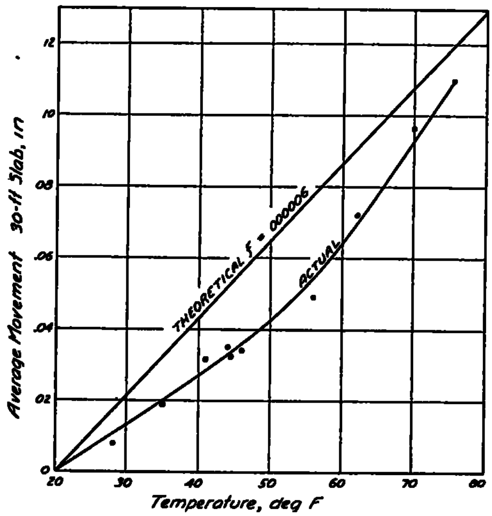

Figure 13. Slab Movements Across Joints

SEALING OF JOINTS

To be sure of obtaining satisfactory results when constructing concrete pavements without steel requires careful thought and control. Not only must the temperature conditions at time of construction, etc., be given particular note, but detailed maintenance must follow the building of the pavements to be sure the conditions on which the design is founded endure. All joints must be carefully sealed immediately after construction and maintained in this condition. The D. C. Department requires all transverse contraction joints to be edged so that they will be open at least ¼ in. for a depth of 1 in. to permit of proper sealing (Fig. 14). This sealing requires the use of a material that will adhere to the sides of the joint at all times and not fail when the joint opens. Should fine inert material be permitted to fill the joint, the designed allowance for expansion of the concrete would be decreased and such subsequent expansion as might be caused by changes in temperature and moisture might create compressive stresses in excess of the endurance limit of the concrete and result in early failures.

The necessity of using a joint seal to provide for the continued satisfactory performance of concrete slabs cannot be overemphasized. In fact, there is probably no single construction detail which could serve to offset the stress calculations and design

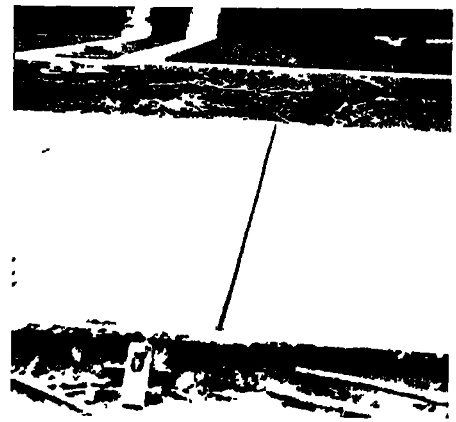

Figure 14. Edging of Joints to Provide a Well for Sealing Material

considerations as the failure to provide an adequate seal.

Uniformity of subgrade condition is the important factor in providing a satisfactory foundation for a pavement surface; and particularly is uniformity of subgrade necessary at joints—where there is always the tendency to curling, heaving, or settlement, due to variations of moisture and temperature and deflection under loads. To seal all joints and thereby a water-proof surface is the best insurance for satisfactory foundation or base conditions that will be reflected in longer life for pavement surfaces.

RIGID TYPE BASES

Further application of the use of closely spaced contraction joints may be found in the construction of rigid type bases.

In the construction of a bituminous pavement on a concrete base, as in all structures, the stability of the surface is retained only so long as the foundation remains intact. Without a doubt, the major difficulty encountered with this type of construction has been premature as well as progressive cracking of the bituminous surface Although failures of sheet asphalt surfaces, as evidenced by cracking, have variously been attributed to the character of the bitumen or the mixture, most surface cracking can be directly traced to failure of the concrete base.

Recognizing the desirability of retaining the distinguishing characteristic of a bituminous surface, that is, its initially smooth, unbroken, and uniform appearance, and further, appreciating that the major portion of irregular cracking of a bituminous surface could be attributed to an inadequately designed concrete base, a study was undertaken by the Engineer Department of the District of Columbia in an effort to develop a design and construction procedure whereby irregular cracking of bituminous surfaces at an early age, with subsequent premature failure and high maintenance cost, could be definitely controlled, if not entirely eliminated.

The presence of irregular surface cracks is undesirable not only because of their unsightly appearance, but more importantly because they represent structural failures Inasmuch as cracks in the pavement surface generally result from underlying base cracks, moisture entering the crack at the surface will penetrate to the base, saturating the concrete as well as the subgrade and thereby cause further disintegration. This problem immediately suggests durability, which is a significant factor in all regions—in the south where repeated wetting and drying occurs, in the north where frozen subgrades may be the major problem, and particularly in the more or less temperate areas where numerous freezing and thawing cycles may occur during the year. In the District of Columbia designs must be made for the latter conditions.

It has been general practice in building portland cement concrete bases for bituminous surfaces, to place the concrete as a continuous slab, that is, without longitudinal or transverse joints; and to use a concrete mix having a low unit cement content (such as four bags per cubic yard of concrete). It is sometimes stated that mixes of low unit cement content are used as a matter of economy Recognizing, however, that the strength of a concrete slab is dependent both upon thickness of section and quality of mix, it will be realized that as the cement content of a given mix is increased the working stress may be correspondingly increased, and, as a result, slabs of a somewhat lesser thickness but of richer concrete may be just as economically utilized. A more valid reason for the use of low unit cement content base mixes has been the desire to minimize volume changes of the base which contribute to its cracking and subsequent failure of the bituminous surface In applying this principle of design, engineers have often failed to appreciate the fatiguing influences on the concrete of a continuous slab as well as the extent to which lean mixes are lacking in durability They have hence given consideration only to wheel load carrying capacity, that is, to the structural strength of the concrete without regard to durability and have advocated the use of relatively thick base slabs composed of low unit cement content while, in fact, thinner adequately designed sections of a higher cement content would have served both to provide adequate concrete slab strength and at the same time greater durability. It is the opinion of this Department that the same consideration should be given to the design and to the quality of concrete for bases as is given to concrete for portland cement concrete pavements.

For some years, it was difficult to provide for expansion of the concrete in bases due to the fact that the premolded expansion joint materials formerly in general use for concrete pavements extruded under pressure and displaced the bituminous surface. Satisfactory non-extruding materials are, however, now available so that adequate provision can be made for expansion of concrete bases.

In developing a balanced design for concrete bases for the District of Columbia, the durability factor of the concrete as well as the structural characteristics of the slab have been considered jointly. Recognizing that cracking of continuous base slabs was inevitable and further that random irregular cracking was undesirable from every standpoint, development of an efficient method for controlling cracking was the major problem. Development of an efficient crack control method was even more essential when durability studies indicated the value of increasing the unit cement content of the base concrete which, however, presaged greater volume changes. Extensive surveys indicated that the major portion of the bituminous surface cracking could be attributed to contraction rather than expansion of the concrete base slab. It was, therefore, evident that study must be given to the effect of contraction, as well as to expansion of the concrete when construction activities are carried on during comparatively low temperatures. These surveys likewise established that stresses resulting from volume changes, unless provided for, will cause cracking and, in cases of considerable expansion, possibly failure due to compression, with the accompanying cracking and surface irregularities in the bituminous top.

Design considerations indicated, however, that if the concrete base could be made to crack transversely at regular and closely spaced intervals, the movement at any one crack would be so small that it would be absorbed by the inherent resilience of the bituminous mixture; further, any cracks which might appear in the bituminous surface would be straight and uniform, and probably so narrow that such mixtures as sheet asphalt would heal under traffic.

Such control of cracking has been accomplished in the District of Columbia by the installation of planes of weakness in the concrete at intervals of 12.5 ft. As in the case of concrete pavements, these bases are put in during the steel shortage with the expectation of maintaining closed joints to provide transfer of load. These planes of weakness are made in the plastic concrete by forming a vertical groove for a depth of at least one-half the thickness of the slab, usually by installing a tough building paper, which is left in place.

When concrete is placed at normal temperatures, the width of the cracks, resulting from hardening shrinkage of the concrete, at closely spaced planes of weakness, (12.5 ft.) is enough to permit any expansion that may occur. When concrete is placed at temperatures below 50 F., expansion joints ($\frac{1}{2}$ in. thick) are installed at intervals of approximately 300 ft.

Where expansion joints are installed the joint filler must be of a non-extruding type and be brought to the surface of the concrete base. Although the bituminous surface will generally crack over these joints, the cracking will be straight and uniform and can be properly maintained (Fig. 15). Before the emergency, this Department was using a thermoplastic rubber compound for the maintenance of such surface cracks. This material does not extrude inordinately under compression and forms a good bond with the bituminous and portland cement concrete. Materials of similar characteristics are again being offered and tests indicate them to be satisfactory.

As previously discussed, surveys have indicated contraction of the base concrete to be the major cause for bituminous surface cracking. In the effort to control, if not entirely eliminate surface cracking of bituminous pavements, the Highway Department of the District of Columbia has experimented over a period of several years with various designs of concrete bases and has obtained excellent results from the application of the transverse weakened plane principle. Besides producing a concrete base which it is believed will have greater durability and longer service life due to the use of a higher unit cement content, the number of surface cracks have been materially reduced and those which do occur permit of satisfactory maintenance.

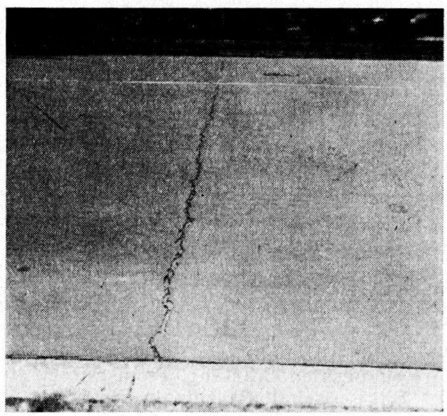

Figure 15. Maintenance of Crack in Bituminous Surface Occurring Over Expansion Joint

The first concrete bases in the District of Columbia with planes of weakness were laid in 1932, with weakened planes spaced at 24-ft. intervals. Although definite control of cracking was noted, with straight easily maintainable, rather than irregular cracks resulting, it was evident that the spacing of the planes of weakness was not close enough to eliminate cracking in the surface of the pavement. Further experiment resulted in the reduction of the plane of weakness spacing to 20 ft.; later, in 1936 to 15 ft., and 1939 to 12.5 ft., as well as improvement in the method of constructing the planes of weakness.

The data presented in Figure 16 illustrate graphically the results obtained in reducing cracking of sheet asphalt surfaces by the installation of closely spaced weakened planes in concrete bases. For the period 1932–35, with spacing of weakened planes at 20-ft. intervals, the average distance between transverse cracks was approximately 55 ft. With the reduction in the spacing of the joints to 15 feet, the average distance between transverse surface cracks was extended to 120 ft., 150 ft. and 245 ft. for projects built during 1936, 1937 and 1938, respectively. The definite drop in the number of surface cracks from

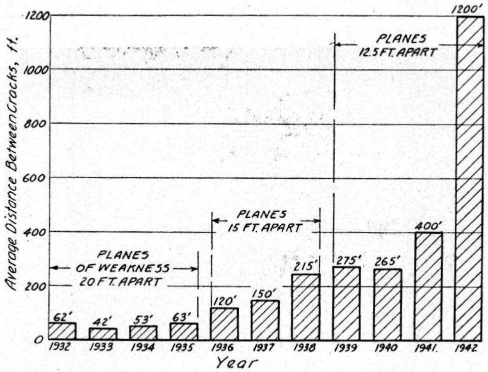

Figure 16. Effect of Close Spacing of Planes of Weakness on Cracking, From Survey of Sheet Asphalt Pavements, Nov. 1943

1935 to 1936 was undoubtedly caused by the reduction of the spacing between planes of weakness to 15 ft., as well as more efficient construction of the planes of weakness. The distance between joints was further reduced to 12½ feet in 1939, which has provided quite general control of surface cracking as indicated by the survey data.

Survey data indicate that the greater percentage of surface cracks which appear in sheet asphalt pavements will be found the first year after placement and that few surface cracks will appear subsequently. Many projects have been completed under the present District of Columbia specification, for spacing of joints in which no surface cracks whatever have occurred.

This method of design and construction of portland cement concrete bases is accomplished with little if any additional contract cost, and results in a considerable reduction in the cost of maintenance. By using a greater unit cement content, this design insures greater durability without causing excessive internal stresses, elimination of irregular and free corners at cracks which generally result in structural failures, and provides a base of uniform supporting capacity. Likewise, it preserves the smooth and uniform appearance so desirable and attractive in bituminous surface pavements (Fig. 17). The combination of these factors will undoubtedly insure a longer life and more satisfactory service for such types of pavement.

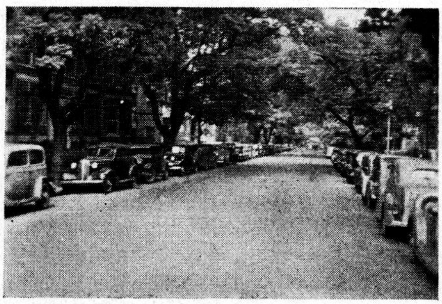

Figure 17. A Smooth Uncracked Sheet Asphalt Pavement

POSTWAR DESIGN OF CONCRETE PAVEMENTS

The Department of Highways of the District of Columbia believes the best practice is to design for free slabs, even, when steel is available for load transfers, so as to insure free movement of the concrete under the natural influences of load, and moisture and temperature changes; and to limit the slab length to a practical minimum so as to reduce internal stresses caused by warping, etc. Short slabs assist in insuring free movement of the slab, especially under conditions in municipalities. This Department recommends the use of reinforcing, mesh or bar mat, though from the purely design standpoint, the use of reinforcing may not be necessary for a length of slab of only 15 feet (Fig. 18). Design of longer slabs should include reinforcing and the length of the slab would be dependent upon the amount of reinforcement used. A comparatively small amount of steel can and does make a good road much better. The use of reinforcing in pavements does not add appreciably to its structural strength, as in buildings, but does increase cohesion of each slab in the pavement; at first in the curing stage when the concrete itself is least resistant to stress and later if cracks occur to check their spreading and prevent progressive failure Reinforcing is believed to be of particular value in distributing the shrinkage stresses which occur during hydration or hardening of the concrete. As an example, it is of interest to report on the success obtained by the installation of wire mesh (20-lb. "chicken wire") around all structures such as manholes, utility poles and projections through the concrete slab. A few years ago there was an unusual number of failures occurring around such structures. Expansion joint material of the old pre-molded type was being placed around the structures before placement of the concrete. A study of the conditions indicated, however, that these cracks were undoubtedly due to shrinkage during hardening of the concrete rather than excessive expansion. The method which has been followed for several years requires only the painting of such structures with a heavy coat of asphalt to prohibit bond between the structure and the concrete when concrete is placed during the summer months; and the use of only four thicknesses of subgrade building paper placed around the structures when the concrete is placed at temperatures of 50 F., or below The wire mesh (2 yd. square) is placed near the surface of the concrete where the first effect of drying out and temperature changes would take place. The use of this mesh has practically eliminated cracks around such structures. Its effect is believed to be in distributing the shrinkage stresses during setting of the cement and the elimination of incipient cracks which are so liable to show at that time and later develop into failures. It is believed that the wire mesh used in pavement construction may act in a similar manner during the setting of the cement. Though the length of pavement slabs constructed by this Department was 30 ft. for several years preceding this emergency, the development of a structural crack or failure in such slabs is practically unknown. The value of reinforcing in holding sections of concrete intact when cracks do occur is well

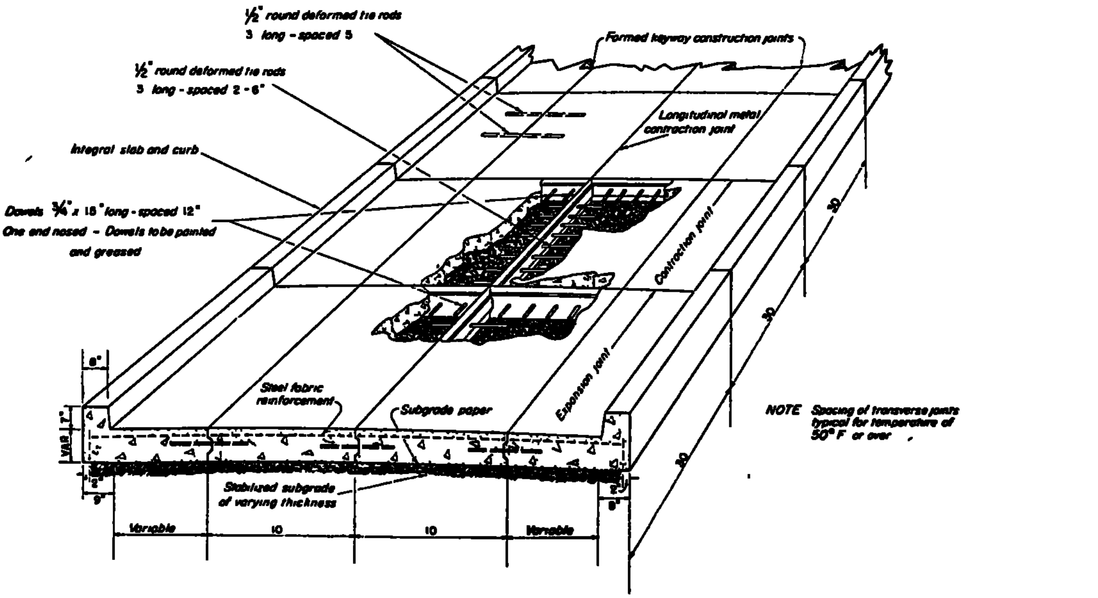

Figure 18. District of Columbia Recommended Design of Reinforced Portland Cement Concrete Pavement

known, but its value in preventing incipient cracks which might develop during hardening of the concrete and later into failure of the slab is not generally appreciated.

CONCLUSION

In the present-day design of pavements, proper design and installation of joints is recognized as the most important factor influencing rigid pavement performance. However, the variations in spacing of transverse joints are as great as at any time, and range from 15 feet to none. It is believed, however, that results from the experiments now being conducted and the study being made of pavements constructed under varying design principles will bring about more uniform practice and it is the belief of this department that practice will specify short slabs with well distributed reinforcement and with well constructed and well maintained joints. The cost of such construction is small in comparison to the insurance provided. Post-war building is going to demand careful consideration of our spending to guarantee the greatest possible economy—not merely low cost.

TRANSVERSE JOINTS IN THE DESIGN OF HEAVY DUTY CONCRETE PAVEMENTS

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SYNOPSIS

This paper is an account of experience with concrete pavements in New Jersey. The situation of New Jersey is such that it is an ideal laboratory for the purpose of quickly and thoroughly testing designs of concrete pavements. Transverse joints, cracks, and pavement design are discussed as relating to ability to sustain the amount of heavy traffic using the State Highway System. Main conclusions reached are:

(1) Heavy duty pavements require designs that provide load distribution at all joints and cracks.
(2) Joint structures should be designed to reduce dowel restraint to the lowest practicable limit.
(3) Surface water should be excluded from access to subgrade in so far as practicable
(4) The surface on which the pavement is laid should be non-erodible, have high bearing value, and preferably be somewhat porous.
(5) Earth infiltration in open joints and cracks leads to spalling, blow-ups, and destruction of load transfer often accelerated by pavement growth.
(6) Joint fillers should fill the joint space at all times.
(7) The use of precompressed wood should be tried extensively for joint fillers.
(8) Contraction joints are unsuitable for heavy duty concrete pavements and warping joints appear to be undesirable.
(9) Concrete sills may be a better load distributing device than steel dowelled structures.
(10) Consideration toward the early abandonment of the free end theory in construction of concrete pavements and adoption of the controlled compression theory, in which pavements are kept under compression at all times by the use of spring dowelled joint structures, is suggested as being more in accord with concrete's inherent characteristics

The material for this paper has been drawn largely from experience gained in studying the performance of concrete pavements on New Jersey's state highway system