

mon problems. One of the primary values of the demonstration projects included in the first year of activities of the public works highway program is largely in the opportunity it has presented to develop this requisite co-operation and to prove its results both to the highway builders and to the public. It is the confident expectation of federal authorities that the results will be generally satisfactory and that what is now a national demonstration will very quickly become an accepted policy.

WORK-RELIEF VALUE

Highway building today should have the goal of creating employment, but an objective of equal importance should be the improvement of roads that will constitute an effective answer to the problem of traffic safety. It is of particular interest at the present time that approximately two-thirds of the roadside improvement expenditure goes DIRECTLY to labor on the local job, while a large part of the remaining third goes to labor employed in growing and supplying plant material. Roadside development, being so largely handwork, affords unusual opportunities for state, counties, and cities to distribute and spread work-relief to various classes of labor.

A well-balanced program of roadside operations directly utilizes unskilled labor to a maximum degree. More than 90 per cent of every dollar spent for this kind of constructive work ultimately arrives in the pay envelope of labor. Roadside improvements are productive and useful work, which provide most effectively for the direct employment of local labor and at the same time also create tangible values of a reasonably permanent nature to be shared and enjoyed by every citizen.

Roadside improvements have a definite place in any program planned for the accomplishment of these common objectives for the public good. The development of these principles will assure an American type of highway for America.

WHAT IS NEW IN CONCRETE PAVING PRACTICE

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The history of concrete paving practice in the United States may be summarized by stating that it first went through a period of slow development with relative uncertainty as to the adequacy of various construction practices, then through a period during which some of the most troublesome uncertainties were eliminated by empirical methods, and finally through a period of development and application of scientific principles.

The advancement of knowledge of a given subject is dependent upon the use made of information already available and the amount of energy expended in the pursuit of further knowledge. It is quite natural, therefore, that the initial period of development and progress was slow. That the initial period of development of concrete paving practice was not of greater duration is due without question to the knowledge gained from the Bates Experimental Road and to the store of information which has become available because of the impetus given to further research by that project.

Upon completion of the Bates Experimental Road investigation, many different agencies started investigations of the many problems which were indicated during the progress of this work. The effect of loads, the problem of subgrade reactions, the subgrade itself, the composition of the concrete, the effect of temperature, and many other problems were subjects of intensive study. Mathematicians have been occupied in the theoretical analysis of stresses in the slab with the result that concrete pavements may now, to some degree at least, be designed rationally in much the same manner as other engineering structures.

While some of these studies have led to more advanced practices in concrete pavement construction than are applicable in the case of some other types of construction, I do not intend to convey that the ultimate has been reached and that there is nothing more to be desired in the way of improvement. There are still many features not thoroughly understood and these must be studied and solved before the ultimate can be approached.

In discussing some of the more recent practices in concrete pavement construction, it must be remembered that in general these are not new developments; back of all of them is previous research and experience and these developments may be considered as the natural outgrowth of this research and experience. Some practices being followed at the present time may be considered as an outgrowth of the existing economic situation, perhaps not strictly in accordance with sound engineering principles, and these no doubt should be considered temporary in character.

SUBGRADE

Subgrades have without question received less attention from highway engineers than their importance warrants. Information relative to soils has been available for a number of years, but practical use has not been made of it until very recently. During 1932 thirteen states had soils organizations, and this number has now grown to thirty. We have learned through costly experience with fills and fill materials not properly placed or settled before the concrete slab is constructed that uniformity of both construction and materials

is of first importance, a fact further emphasized by theoretical consideration of the stresses in the slabs due to loads.

As a result of pavement failures due to subsidence of fills, the practice of settling fills by watersoaking has spread, although in some cases fills are still left to settle naturally before the pavement is constructed, a practice that has many objections. At the present time much thought is being given to the construction of heavy fills in thin lifts, thoroughly compacting each lift, by which method the segregation of dissimilar soil types in various portions of the fill is prevented



Fig. 1. Compacting subgrade with Sheepsfoot roller.

(Fig. 1). Experience in Illinois has indicated that more uniform and satisfactory results will be obtained and that a saving in construction costs will result from this practice.

Little effort has been made on the part of most of the states to obtain uniform subgrade conditions by studying the characteristics of the soil types, although many states are now giving this question serious consideration. It has been general practice, and still is in many states, to permit traffic on the prepared subgrade for the purpose of hauling materials and then to attempt to remedy the damages resulting therefrom immediately before the concrete is placed. The ruts formed by this traffic and by the mixer operating on the subgrade are filled with earth and tamped. Such practice produces general non-uniformity in the compaction of the subgrade, and failures which may be attributed directly to this practice have resulted in many cases. There is a trend toward prohibiting traffic of any kind on the prepared subgrade and operating the mixer from outside the forms (Fig. 2), exception being made only in instances where it is physically impossible to operate outside of the forms, as in the case of cuts and fills. This practice does much toward producing a more uniform subgrade as far

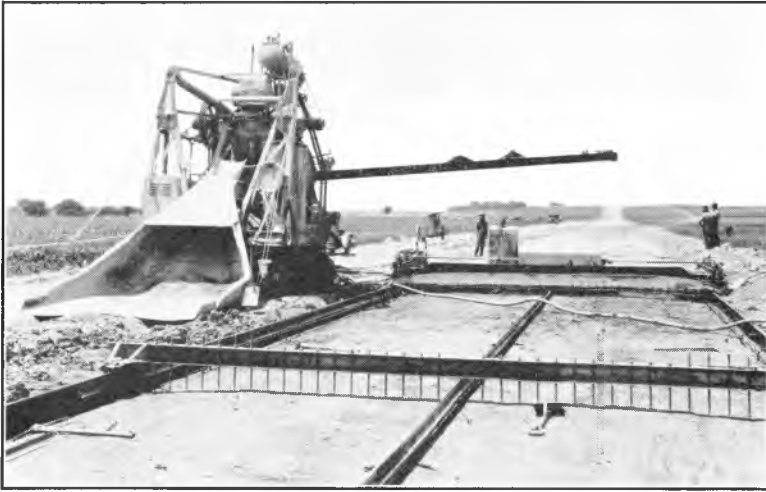


Fig. 2. Mixer working from shoulder.

as compaction is concerned. Whether the improvement of subgrades by the addition of other materials to stabilize them can be justified economically remains to be determined. In the meantime, any practice which will produce subgrades having uniform physical properties and retain them is a step in the right direction.

PAVEMENT

While the general design developed by the Bates Experimental Road has been adopted almost universally, improvements are still being made and new features introduced. The depth of the slab is being increased to provide additional protection against the operation of overloads which cannot be controlled by policing and to afford additional resistance to the effects of weathering. Changes such as this may be considered as the result of experience and observation of existing pavements rather than of research and theoretical considerations.

Recently a new type of longitudinal center joint has been proposed and adopted by some states which provides a continuous bar interlaced through the joint in place of the tie bars used generally heretofore. This design has been found to possess desirable qualities as far as construction operations are concerned, and it also affords better distribution of steel along the center joint.

Smoother pavements are being obtained than ever before, although some retrogression, due to the necessity of using local labor which is generally inexperienced, may be expected in this respect. It has been found extremely difficult to obtain

sufficient skilled local labor to produce the desired degree of smoothness and surface finish.

The opening of concrete pavements to traffic on the basis of field strength tests is a practice which is gaining favor rapidly among highway engineers. The opening of pavements on this basis seems logical, and while some objections may be offered because the test specimens cannot be cured in identically the same manner as the pavement slab, experience in Illinois at least has indicated that this practice is safe. A modulus of rupture can be selected which is sufficient to take care of any difference which might be assumed to exist between the test results and the strength of the concrete in the pavement slab.

Recently one section of pavement was cured in Illinois by means of a saturated mat covering protected by rubberized cloth. This type of mat contains numerous cells for the retention of water, while the fibers from which it is made are in themselves non-absorbent. Beam specimens were cured in both moist sand and under the cover. The mat was left in place for three days, and when removed contained a considerable amount of the original moisture. Upon removal of the mat, the beam specimens which had been cured under it were placed along the edge of the pavement and banked with earth, only one surface of the specimen being exposed. It may be assumed that the slab, being a continuous mass, was cured at least as satisfactorily as the beams placed along its edge. These test beams showed an average strength of about 94 per cent of that obtained from the beams cured in moist sand. If the mat had been left in place more than three days, still better results should have been obtained. Temperature measurements under the mat showed that it possessed some protective properties which might be used to advantage in late fall construction, although this was not investigated sufficiently to make a definite statement. It would also be desirable to make further tests during extremely hot and dry weather.

EXPANSION AND CONTRACTION JOINTS

One of the most important changes in paving practice in Illinois during the past two or three years has been the adoption of the use of a new type of joint to take care of expansion and contraction in the concrete (Fig. 3). During the period of intensive construction of concrete pavements in Illinois, neither expansion nor contraction joints were used. Illinois, like many other states, proceeded on the theory that it was more economical to permit cracks in the newly constructed pavement to occur naturally than to provide for expansion and contraction. Furthermore, it was the belief that no satisfactory type of expansion and contraction joints was available.

That the use of the transverse joint is not of recent origin is evidenced by the fact that some of the oldest concrete pave-

ments were provided with such joints. In Professor Ira O. Baker's *Treatise on Roads and Pavements*, which was first published in 1903, a section is devoted to the subject of contraction joints in portland cement concrete roads. In view of

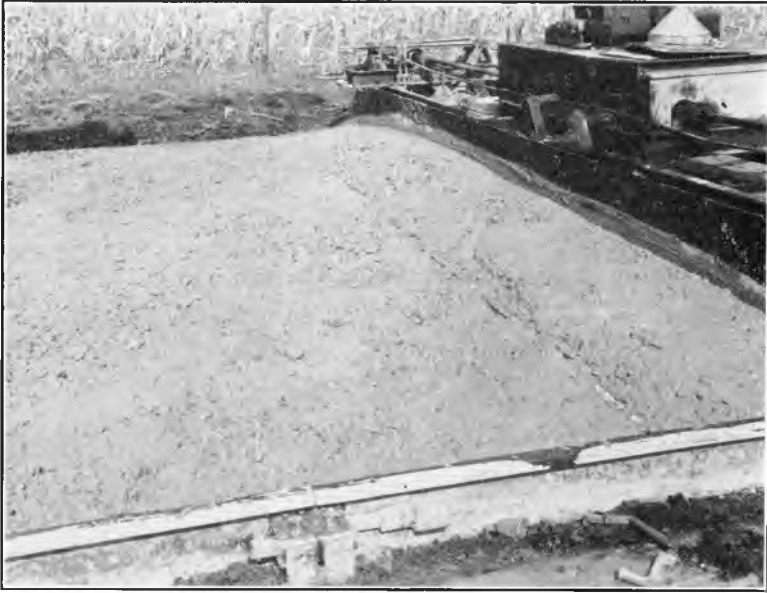


Fig. 3. Placing concrete around transverse joint.

our present knowledge of the use of expansion and contraction joints, a quotation from this section is interesting:

“Concrete expands and contracts with changes of temperature and moisture. Since the pavement is ordinarily laid in warm weather, the contraction is likely to be greater than the expansion; and besides the concrete can resist the compression due to expansion better than the tension due to contraction. To prevent the formation of unsightly and irregular cracks due to contraction, it is customary to provide contraction joints at regular intervals. If the pavement has curbs, longitudinal contraction joints are also provided at each curb. Concrete roads and pavements are usually provided with transverse contraction joints from 25 to 75 feet apart, usually 50 feet.

“Sometimes the contraction joints are placed on an angle with the length of the road, which is an advantage if there is either an elevation or depression at the joint; but if the joints are properly made and maintained, the extra length is only a needless expense, and besides it is very difficult to strike the surface adjacent to the diagonal joint.

“A number of attempts have been made to determine mathe-

matically the proper distance between contraction joints; but there is so much uncertainty in each of the factors of the problem that any such computation is practically worthless."

One type of transverse joint described by Professor Baker consisted of a soft steel $\frac{1}{4}$ -inch plate on each side of a $\frac{1}{4}$ -inch sheet of mastic. The plates were provided with projections to tie or bind them securely to the concrete. Some joints of this type were actually installed in some of the older pavements in Illinois and were known as "armored" joints. As noted in the above quotation, it was thought that joints of this type placed at an angle provided better riding qualities, and it was further the belief that this feature would result in a slight lateral displacement of the pavement during periods of expansion rather than compression failures in the form of blowups.

The belief that transverse joints were necessary, or at least desirable, therefore, has occupied the minds of some engineers practically throughout the entire period through which concrete pavements have been constructed. For several years, however, the opinion prevailed that transverse joints in rural pavements, while perhaps desirable, did not provide benefits commensurable with their cost. The objections chiefly voiced were that they did not reduce the total number of transverse cracks, each joint being considered as the equivalent of a crack; that the construction technique and the fact that the joint fillers extruded produced rough riding pavements; and that failures due to heat expansion could be repaired with far less expense than the incorporation of joints.

Perhaps the unsuitability of various premolded joints and joint fillers developed during the past decade was partially responsible for the unpopularity of transverse joints in concrete pavements, but it was not until the behavior of large mileages of concrete pavements had been studied for several years that the need for such joints was thoroughly understood. Not only was it shown clearly that any transverse crack was a weak point in the slab, which properly should be taken care of in design, but it was found that compression failures due to heat expansion increased with the age of the pavement. Furthermore, the frequent occurrence of blowups became a great menace to the traveling public.

All pavements, practically without exception, need some expansion space. Even though they may be constructed when temperatures are the highest, the curing methods generally employed will not permit a pavement to set in its most expanded condition. If the pavement is not kept wet, shrinkage will occur during setting which will result in transverse cracks; and when subsequent contraction due to low temperatures occurs, further transverse cracking will occur. These cracks, alternately opening and closing, will in a few years become filled with foreign material and occupy the expansion

space provided by such cracks, and blowups will follow shortly thereafter. The sealing of cracks with asphalt or other material has been found wholly ineffective in preventing the entrance of water and the infiltration of foreign materials. Obviously the only remedy is to provide at proper intervals sufficient unobstructed expansion space which cannot be filled with foreign materials.

But this is not the only reason for the need for transverse joints. It was mentioned previously that any transverse crack constitutes a weak point in the slab; that is, two edges of uniform thickness not mutually supported. That edges of the same thickness as the center of the slab are weaker than the center is recognized in thickening the outside edges. In order to prevent such weak places in the pavement, it is obviously necessary to predetermine the locations of the cracks and insert proper load transfer devices at such places.

While joints of the premolded type and those employing poured fillers have been used in the past, the material used in such joints will compress more or less permanently or extrude when the pavement expands; and when the pavement contracts, it will not fill entirely the space originally occupied, leaving some space which will be filled with foreign materials. Repeated expansion and contraction of the pavement will eventually permit sufficient foreign material to enter the joint to render it of little value. The most that can be said for such joints is that they delay the failures of the pavement which inevitably must occur.

During the year 1928 the U. S. Bureau of Public Roads, in co-operation with the Illinois Division of Highways, made a complete condition survey of 1,140 miles of concrete pavement in Illinois. On 310 miles of this pavement built between the years 1919 and 1928, 61,721 transverse cracks had occurred at an average interval of 27 feet; 229 blowups had occurred, or one to every 1.35 miles of pavement. On the remaining 830 miles built between the years 1923 and 1928, 84,561 transverse cracks had occurred at an average interval of 52 feet; 258 blowups had occurred, or one for each 3.22 miles. The survey indicated that the number of transverse cracks and blowups increase as the age of the pavement increases.

Because of the large number of transverse cracks and blowups in the pavement due to expansion, the Division of Highways in 1928 adopted the practice of constructing in the pavement 4-inch open joints at intervals of from 800 to 1,000 feet, later filling them with asphalt. These open expansion joints were not installed with the idea of preventing the extensive cracking which takes place, but to prevent or delay the occurrence of blowups.

During the year 1932 a detailed examination was made of the pavements which had been built up to that time. Be-

tween the years 1922 and 1931, 4,633 miles of pavement had been constructed without expansion joints, and during that period of time 3,940 open expansion joints had been cut into the pavement to relieve expansion forces. Nevertheless, 3,400 blowups occurred, or one for every 1.36 miles, a close check of the interval determined by the previous survey. Four-inch open joints had been installed in 3,417 miles of pavement, and measurements of these joints indicated clearly that they were closing at the rate of approximately one inch per year, so that at the end of a 4-year period they would be practically closed. Therefore, the use of the 4-inch open joint spaced at long intervals simply prolonged for about four or five years the time before blowups might be expected to occur.

Up to this time no satisfactory type of expansion joint designed to be installed at close intervals had been proposed. It is true that one particular type of joint had been proposed for a number of years but it had not been perfected to the point where it was of any practical value. After thoroughly considering the data gathered by investigation of the pavements already constructed, it was decided early in 1932 to install experimentally as many different types of expansion joint as were available, and to observe their action with the idea of changing our policies relative to the use of expansion joints.

The practice of installing 4-inch open joints in the pavement and the noticeable defects of these joints had interested a number of commercial concerns in the design of a mechanical joint to replace the open joint. It was thought that if a satisfactory type of mechanical joint could be developed, the intermediate cracking could be controlled by proper contraction joints. Altogether, ten individual types of joint, manufactured by nine different concerns, were installed in about thirty miles of pavement. With the exception of two of these types, however, they were all designed to be installed at long intervals and no provision was made to prevent the formation of natural cracks between the expansion joints. Of these two types, one consisted of the regular premolded expansion joint which had been in use for a number of years and the other was a type of all-metal, air-chamber joint. Careful examinations of these installations were made periodically, and it soon became evident that the expansion joints spaced at long intervals were not satisfactory and that this type could not be used successfully for the reasons already mentioned. Furthermore, all of the joints designed to be installed at long intervals showed mechanical defects which would prohibit their successful use. Out of all these installations only one type of joint, namely, the metal air-cushion joint, showed promise. Certain defects appeared in this joint during the installation, but these were of such nature that they could be and were subsequently corrected.

In addition to the expansion joint a satisfactory type of contraction joint was offered. During the year 1933 this type of joint was installed in approximately 350 miles of pavement. During the latter part of 1933 another joint involving similar principles, but with a different method of load transmission, was installed experimentally in about ten miles of pavement. Several defects appeared in this joint during the installation, but these were corrected and the joint admitted for general use during the early part of 1934. A considerable mileage of pavement was built during 1934 including this type of joint. Further defects were disclosed during the installation on a large scale, the correction of which is under consideration at this time.

Another type of air-cushion joint was installed experimentally in 1934, and this has just been approved for use, so that at present we admit three different types of expansion joints, all of which utilize the air-cushion principle.

All these joints possess the common feature of a U or V-shaped copper seal across the top of the joint, which seal is bonded with the concrete on each side of the opening. In two of the types, this seal is extended across the ends to provide a watertight end closure. On the third type, a sliding end closure is provided. These features permit a change in the width of the joint without injury to the seal and definitely prevent the entrance of water and the infiltration of foreign material through the top and ends. In the expansion joints, the expansion space is enclosed by thin steel side walls and bottom, the side walls serving as a form against which the concrete is deposited. These side walls are merely for construction purposes and are of no use after the joints are properly installed.

The contraction joints initially contain no expansion space. They consist essentially of a strip of metal holding the copper seal in position while it is being placed in the concrete. The strip of metal need not necessarily be continuous, and it either produces a weakened plane which will result in a transverse crack or it may extend to the subgrade, thus forming the joint.

Both expansion and contraction joints are provided with a load transfer device. Two of the types employ dowel bars alternately bonded to one or the other side of the joint and free to slip at the other side. The other type employs a load transfer device consisting of structural steel angles in short lengths placed alternately in such a manner that one leg is fastened into the vertical face of the concrete on one side of the joint by means of lugs cut from the angle and bent so that they may be embedded in the concrete, and the other leg extends under the concrete on the opposite side of the joint. The angles are alternated in order to provide load transfer from either side. The horizontal projections of the angles are

enclosed in a metal sleeve to provide for movement of the angles.

For protection either the copper seal on all types of joint is covered with a premolded bituminous cap left in place or a suitable poured filler is applied. Expansion joints are spaced at intervals of ninety feet, with two contraction joints between, providing a maximum panel length of thirty feet.

As mentioned in the quotation from Professor Baker's book, it is practically impossible to determine the spacing of joints mathematically. The spacing which we are using in Illinois was determined from the results of the crack survey previously mentioned and represents our best judgment as to the panel length which will function without the formation of additional transverse cracks.

Investigations are under way to secure definite data relating to the cracking which has occurred in the pavements in which joints have been installed. In most of the instances where cracks have occurred between joints they are clearly the result of adverse subgrade conditions. At present it is quite definitely established that essentially all cracking between joints occurs on fills and in cuts and that serious cracking has occurred only over deep fills. It is estimated that between two and three times as many cracks have occurred on fills as in cuts, and that where there is no fill or cut of any consequence cracks occur at the rate of only about one to each 3,000 joints. The few cracks which have occurred outside of fills and cuts are nearly all at points of non-uniformity of subgrade, such as at culverts. The fact that transverse cracking is not wholly controlled by the joints where the pavement is placed on fills and in cuts indicates that soil studies may profitably be made to determine the proper steps for their prevention.

Some warping or heaving of the slab has occurred adjacent to some of the joints installed during 1933 which did not have watertight end closures. These defects were not apparent during the first winter, but weather conditions have been such during the fall and winter of 1934-1935 as to promote warping. This indicates that difficulty will be encountered with warping or heaving if the top seal and end closures at least are not made watertight. It is not sufficient just to exclude foreign material. It might even be necessary in the case of certain soil and drainage conditions to seal the joint completely. We are now conducting a thorough investigation of the cause of the warping which has occurred and data relative to this will be available later.

The whole subject of expansion and contraction joints is very interesting and much time might be spent in a technical discussion of the action of concrete due to temperature changes and the effect of weathering, the necessity for joints, and the details of the design of joints and their installation. The

subject, however, is far too comprehensive for any further discussion in this paper.

VIBRATION OF CONCRETE

Placing concrete mixtures with vibratory equipment is a comparatively recent development, although, as in case of joints, the principle is not new and was tried experimentally on laboratory specimens more than a decade ago. The successful placing of mixtures by vibration under actual construction conditions, however, has depended upon the development of proper equipment with which to perform the operation satisfactorily.

The compaction of concrete in structures by vibration is at present required in many states; the compaction of pavement concrete by means of finishing machines equipped with vibratory screeds is, so far as known, required in only one state. Illinois requires vibration of concrete in all structures having



Fig. 4. Placing concrete in a structure by internal vibration.

a span of twenty feet or more (Fig. 4). For smaller structures hand and vibratory methods are optional with the contractor.

One season's construction has been completed under these specifications, and while a complete study has not been made of the data obtained it is felt that vibration is far superior to hand methods in consolidating the concrete. On the other hand, it has become apparent that knowledge of the vibratory equipment employed in this work is inadequate. In case of many of the vibrators it is felt that there may not be sufficient power behind the vibration and that there may be a too pronounced damping of the vibration when the vibrators are inserted into the concrete.

Various suggestions, such as limiting the output of concrete or limiting the size of mixer, have been considered; but it is felt that before such suggestions can be considered seriously some additional information must be obtained. To this end we are procuring vibrating reed tachometers for studying the frequency of vibration obtained with the equipment employed.

The selection of concrete mixtures for use with the vibratory equipment has been characterized by a certain conservatism. It is quite possible that the full benefit in saving of cement without reduction in quality of concrete has not been realized through the use of the vibratory equipment. It is felt, however, that conservatism is desirable so long as the method of procedure is experimental or semi-experimental, especially since the concrete in test specimens cannot be vibrated in the same manner as that in structures.

On the average, therefore, the weight of sand per bag of cement has been kept about the same and the amount of mixing water about the same or a little less than when hand methods are used, whereas the amount of coarse aggregate has been increased to conform with the ability of the equipment to place the mixture. The consistency of the concrete was varied to suit the particular condition, the slump ranging from one to four inches with an average of two and one-half inches. Probably the saving in cement did not exceed one-fourth bag per cubic yard of concrete.

Under these conditions it would be expected that the quality of the concrete obtained would be at least as good as that obtained by hand methods. That the consolidation obtained was better could be seen both by observation of the placing of the concrete and from the appearance of the finished product.

Tightness of forms is much more important than when hand methods are used. Any opening will cause leakage of mortar from around the coarse aggregate, resulting in a small area of honeycombed concrete at such point. Small air bubbles between the form and the mass of concrete which mar the appearance somewhat seem to be a natural consequence of this method of placing, but these have not presented any particular problem. A large percentage of these may be removed on exposed surfaces by rubbing.

The rapidity with which vibratory methods of placing concrete in structures have been accepted by engineers and contractors alike indicates that the method is not only sound from an engineering standpoint, but that it is equally justifiable from the standpoint of savings in the cost of construction operations.

The use of vibratory methods of placing concrete pavements has not received the universal acceptance accorded the internal vibration employed for structures. Since a pavement

is relatively thin, internal vibration is rather impracticable, except where it may be used to advantage in consolidating the concrete at localized points, such as at expansion and contraction joints, adjacent to the longitudinal joint, and along the forms. The vibratory units are in general placed on top of the screeds, imparting to these the properties of both screeding and vibrating simultaneously.

Although development of other types of vibrating units has been reported, the vibration used in placing concrete pavement up to the present time must in general be classed as external vibration, it being applied to the surface of the mass and not to its interior.

The advantages which result from external vibration in placing concrete pavement are well known. Since drier consistencies may be used, either the water-cement ratio may be decreased, resulting in higher strength concrete; or the amounts of aggregate may be increased, resulting in a saving of cement; or a middle course, that of decreasing the water-cement ratio and increasing the amounts of aggregates simultaneously but to lesser degrees, may be followed, resulting in both increased strength and saving of cement. This not only follows from the fundamental principles of design of concrete mixtures, but has also been shown through investigation performed by three or four states to study the merits of this method.

Illinois undertook an investigation during the month of August, 1932, and included the construction of about one mile of pavement, consisting of 114 individual sections and nearly as many different mixtures, duplications being made in a few instances. Both gravel and crushed stone coarse aggregates were used. The finishing machine was essentially a standard type with the screeds designed in a slightly different manner. Three vibratory units, which operated at about 3,600 impulses per minute, were placed on the front screed and two on the rear screed. (Fig. 5.)

The design of the mixtures was varied to show not only the most suitable proportions but also the limitations of the equipment. The quantities of aggregates per bag of cement were varied approximately from 180 to 265 pounds of sand, from 320 to 510 pounds of crushed stone, and from 360 to 540 pounds of gravel, the larger quantities of sand in general corresponding to the larger quantities of coarse aggregate. The cement content was varied approximately from 1.1 to 1.5 barrels per cubic yard of concrete. The amount of mixing water for standard strength was in the vicinity of 5.33 gallons per bag of cement, but had to be increased for several of the harsher mixtures in order to place these satisfactorily.

It was found that standard strength was in general obtained where the mixing water was not increased above the specified amount, and that satisfactory consolidation of the concrete was obtained in all instances. The most suitable

mixtures were of about one-half inch slump and contained a ratio of sand to total quantities of aggregates of 32 to 35 per cent. A reduction of about 15 per cent from the amount of cement used with ordinary equipment was obtained without sacrifice in quality of the concrete.

Favorable results have been obtained from similar investigations by others, and while this method of placing concrete pavement has not been widely accepted, that fact cannot be attributed to the fact that the benefits which can be derived from it are unknown. It is rather that some uncertainties still exist which warrant further preliminary work and perhaps also the equipment used may not be considered as fully developed.



Fig. 5. Vibratory finishing machine used in experimental construction. Note man walking on top of mixture.

With the information already on hand relative to the placing of concrete mixtures by means of vibration capable of being used as a basis for further investigation, it is to be expected that many improvements, both in equipment and methods, will follow shortly. It is probably also safe to predict that vibration will be the chief means of compacting concrete in the near future.

CONCLUSIONS

In concluding this discussion it is desired to emphasize that the satisfactory application of new principles in practice is the beginning of a period of development toward perfection; or, in other words, the finding, consideration, and correction of the points which contribute toward perfection. This is true in case of almost any research problem. Co-ordination of efforts is therefore essential. The engineer in the field who has the opportunity of observing practical application

every day should be in close co-operation with his colleagues in design and research work, who are generally of more theoretical turn of mind, but who do not have the opportunity of prolonged observation of the practical application in the field and often do not appreciate sufficiently the problems involved. There can be no questioning of the fact that knowledge already at hand, properly co-ordinated, analyzed, and understood, is the most powerful tool available for further development.

LOW COST BITUMINOUS ROADS

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The ever-increasing demand of the traveling public for roads usable in all weathers—smooth, dustless, and safe—has added greatly to the responsibilities and problems of all agencies of government charged with the construction and maintenance of roads.

It was apparent some years ago that the revenues available would not permit extensive construction of so-called high-type surfacing (even in states where large bond issues were voted) with any hope of completing the job. This was essentially true of states that were proceeding on the “pay-as-you-go” plan. In an effort to solve this complex problem the different states turned to cheaper materials of all kinds with results which in many cases were neither pleasing to the traveling public nor gratifying to the state highway departments.

It is my opinion that all of our known surfacing materials have a place in our future road planning throughout the nation, as the spot can be found where some particular material, considered from all angles, will best serve the requirements of traffic service and economy. The object of this paper will be to show that low cost bituminous materials, or, more specifically, liquid asphalts, are no exception; that roads surfaced with such materials at low cost have a definite place in our future road planning and that certain results may be obtained from their use.

The term “low cost” is within itself indefinite, as at best it can be considered only as a relative term, for what is considered low cost by some may by others be considered not only high cost but prohibitive cost—according to funds available and the mileage to be improved or needing improvement.

While in Oklahoma we have constructed asphalt surfaces on heavy gravel and stone bases at costs ranging from \$10,000 to \$14,000 per mile (which we considered relatively low cost roads), I shall confine my discussion to our experience with surfaces and surface treatments which were constructed at an initial cost of \$200 to \$3,000 per mile.