equal since any type which would very much exceed the lower figure obtainable with another type is eliminated

We have recently developed a three-page form by which we can trace the costs per mile and per car mile for any section of road through successive years and changes of type without losing sight of the essential items of depreciation and interest

An illustration of a section of pavement where Type 31, bituminous surface treated macadam on broken stone base, has been replaced by Type 42, reinforced concrete, is given

If we have information from which we can reliably estimate comparative surface maintenance costs and length of life for alternative types of pavement under particular conditions, the problem of selection of type of improvement becomes greatly simplified In case we should be considering the relative economy of two pavements one of which would last longer than the other and cost less annually in maintenance but be higher in first cost, we could take two factors from the proper interest rate column and year line from a table of "Annuities Which I Will Buy," or "rental values" as they are sometimes called, and the difference between these factors divided into the difference in annual maintenance cost would show us the economic difference in value between the two pavements and how much more we could afford to pay for one than for the other

For example, if the comparison should be between a ten-year life, eight hundred dollars a mile annual maintenance, pavement against one of twenty-year life and three hundred dollars a mile annual maintenance, and the construction fund derived from five per cent bonds, the rental factors are $0 1295046 for ten years and $0 0802426 for twenty years, the difference is $0 0492620 and this factor divided into the difference in maintenance, $500 00 a mile, shows that we could afford to pay $10,150 00 per mile more for the construction of the twenty-year than for the ten-year pavement

CONCRETE PAVEMENT MAINTENANCE

LEE S TRAINOR

Portland Cement Association

Studies made by competent observers and research specialists have indicated that inadequate design, and por construction have a very definite influence upon the necessity for and cost of Maintenance of Concrete pavements Also lack of early and intelligent maintenance has an important influence on the cost of further maintenance

Given good materials and having an understanding of the conditions

to be encountered, it is possible to design a pavement to successfully fulfill all of the requirements, but good design alone will not suffice. Proper construction, entailing faithful compliance with all the conditions set up in the design and intelligent, prompt and thorough maintenance must follow to secure the maximum life and value from the structure Design and construction must provide for the structural stability required under the conditions of service and climate to which the pavement is to be subjected

Progressive and far seeing highway departments of states, counties and cities are agreed upon the necessity for practical, intelligent maintenance of all pavement surfaces The technique of surface maintenance on concrete pavement has not been completely standardized and it will not be the purpose of this paper to discuss the subject, except as it may be influenced by those features of design and construction which bear upon the life-durability and satisfactory use of the pavement

Early and proper curing of concrete pavement exerts a profound influence upon the life and durability of the pavement which is reflected in reduced necessity for surface maintenance

Curing which promotes complete hydration of the cement in the mass is accomplished by providing favorable conditions, either by replacing water that has been lost through evaporation or by sealing the surface of the pavement to prevent such loss Several materials and methods of curing are available the most recent developments being in the field of surface coatings designed to prevent the loss of moisture by evaporation

Next in order of importance to curing is early maintenance, again proving the old adage, "A stitch in time saves nine"

During the past year field observations have been made on a large mileage of concrete road pavements to determine their present physical condition under various conditions of traffic and service taking into account climatic conditions, subgrade, materials and methods used in construction, etc. While reports covering these studies have not been completed many significant indications have been already developed.

Among these developments and applying specifically to work in the Northern states will be found indications of necessity for thorough study of aggregates proposed for use in concrete pavement construction to determine their soundness under alternate freezing and thawing.

The Portland Cement Association started about a year and a half ago a study which for the want of a better name, was called a condition survey of concrete roads. Progress today indicates that 3 additional years will be required to complete this study. In the study all features of design, methods of construction, materials, climatic conditions, service and traffic and all of the other significant variables are being taken into account.

The field party consists of five men equipped with an automobile with some special appliances including an instrument for measuring the surface smoothness of the pavements In some cases by permission of the state highway departments we are removing cores from the roads for study The cores of one series have been cut into one-inch thicknesses in order to study separately the condition and character of the concrete at various depths A careful and detailed study is being made with the hope that something that will be of benefit to the road designer and builder, and to the road user, and the man who pays for the road will be developed The field observations have been completed in one central state, one southern state, and one northern state These three states were chosen because they involved different phases of the study, in hope that in such a preliminary investigation something of benefit in carrying on the balance of the investigation would be found

There is also evidence tending to establish the necessity for more complete understanding of details of placing expansion and other joints in the pavement In one study 40 per cent of the expansion joints used in the original construction were found to be defective principally through careless construction The joints were.

(1) Not vertical
(2) Did not extend thru entire thickness of pavement
(3) Did not extend entirely across the pavement
(4) At intersection of compressible and non compressible joints, the Compressible joint filler did not extend continuous across non-compressible joint.

All of these defects which contribute so largely to the surface maintenance required on the pavement should and can be totally overcome by proper installation during construction

Care should be exercised to prevent foreign materials of a solid nature from becoming lodged in the space to be occupied by the joint filler and all such materials should be removed before joints are refilled with bituminous material during maintenance operations

The application of bituminous material to the outside edge of the pavement slab at the outer ends of expansion joints has been found to be effective in preventing foreign materials from entering the expansion joint from the side This result is most easily accomplished by removing shoulder material at the ends of all joints for the full depth of pavement slab and inserting sheet metal or other suitable form to mold a section of bituminous material about 1 inch in thickness and from 3 to 4 inches in length for full depth of the pavement slab After the bituminous material has cooled the form may be removed and shoulder material replaced

It was noted in several instances that short longitudinal cracks in the

pavement originated at transverse expansion joints and investigation established the fact that solid materials were imbedded in or were occupying part of space intended for compressible joint filler and when the pavement came into compression excess stresses were set up at these points resulting in the formation of longitudinal cracks

The unsatisfactory conditions resulting from non vertical joints and uneven height of concrete on opposite sides of expansion joints are too well known for discussion here

The conditions existing at the intersection of compressible and non-compressible joints as observed in the field indicates the necessity for more careful attention to details of construction at these points if maintenance costs are to be held at a minimum

It was found that in many cases compressible joint filler was cut or short sections omitted to permit installation of continuous section of non-compressible joint material resulting in conditions favorable to spalling and as a consequence requiring additional attention and expense for maintenance at these points

A good rule to follow would be "Compressible joint filler shall be so installed as to provide continuous strip across full width and depth of pavement and shall be continuous across all joints where no compressible filler is used "

Concrete adjacent to all joints should be rounded by use of appropriate edging tool to prevent chipping

The replacement of bituminous materials that may be lost from expansion joints under service conditions and the filling and sealing of cracks and breaks that may occur in concrete pavement constitutes the major maintenance activity common to the pavement structure

All cracks and joints should be thoroughly cleaned and old filler and other foreign substances removed before new filler is applied Steel rods with curved sharp points will be found useful in removing imbedded material from cracks and joints Small hand bellows are useful in blowing dust and other fine materials out of joints A hose attached to the exhaust pipe of an automobile may be similarly used and some Highway Departments employ a small portable air compressor mounted on an truck for this purpose

A hot shovel may be employed to remove excess filler after joints and cracks have been filled This procedure not only produces a more sightly appearance but conserves filler material, and improves the riding qualities of the pavement

Asphalts and tars predominate as materials for use as crack fillers However, there are wide differences of opinion among highway engineers as to the relative merits of these two materials as well as many variations of each, which condition suggests the necessity for well directed research in this field

Specifications for bituminous joint and crack filler have been prepared by A S T M. (Tentative Standard D-102-24 T) and by A S M. I (Page 496, proceedings 31st Annual Convention 1925–1926) However, neither of these specifications seem to meet with universal approval

Intelligent use of planes of weakness or dummy joints both longitudinally and transversely has eliminated much if not all intermediate cracking with its attendant call for maintenance

Planes of weakness may be produced by inserting at the time of construction continuous metal or other non-compressible strips set vertical and extending from sub-grade to or near the top surface of the pavement or the same effect can be secured by building the pavement part at a time using properly spaced construction joints for this purpose

Dummy joints are formed by pressing or inserting into the surface of the pavement (while plastic) a thin metal strip about $\frac{1}{4}$ to $\frac{3}{8}$ inch in thickness and from 2 to 3 inches wide which strip is later withdrawn leaving an indentation in the surface of the pavement which is later filled with bituminous filler

Approved modern construction practice does not tolerate surface irregularities greater than $\frac{1}{4}$ inch in 10 feet and an increasing number of Engineers are demanding a maximum tolerance of $\frac{1}{8}$ inch in 10 feet When surface irregularities greater than the maximum tolerance are encountered they should be removed before concrete has hardened if detected in time, otherwise they may be ground down by a power driven grinding machine especially constructed for this purpose.

The prompt reduction of surface irregularities will produce a better riding surface with longer life and satisfactory performance at considerable reduction in maintenance costs

Replacements due to structural failure, service cuts, or other causes are most satisfactorily made with concrete and in those locations where minimum closing to traffic is desirable High Early strength concrete may be employed with satisfactory results In making replacements of this nature the area to be replaced should be as nearly square or rectangular as possible, avoiding acute angles and the sides of the remaining concrete trimmed as nearly vertical as possible for at least 2 to 3 inches down from the top surface of the pavement.

Low Water-Cement Ratio Concrete of a relatively Stiff Consistency Should be Employed in making replacements and all new concrete should be thoroughly rammed and tamped into place the tamping and ramming should be repeated at intervals for 45 minutes or more and new material added if necessary to completely fill the space Care should be exercised to make sure that new concrete is in intimate contact with old material after initial shrinkage has taken place. Normal portland cements may be employed to produce high early strength concrete with entirely satisfactory results.

In cold weather all materials entering into concrete replacement work should be heated to from 70 to 90°F, and provision made to retain heat in the replacement area until the concrete has hardened

A rather interesting study was made in our laboratory last year It was suggested that possibly it might be desirable in winter to preheat concrete aggregates before mixing A short series of test specimens was prepared in three groups, by heating all the aggregates and the water used in the specimens of each group to 70, 150 and 200 degrees Fahrenheit respectively Specimens in each group were made for compression and flexural tests and each specimen was made in duplicate, one to be cured in a moist room and the other to be cured on the roof of the building at winter temperatures The temperatures during the tests ranged from about 10 degrees above zero to 35 degrees above zero It was found that, in those cases where the aggregates were heated to 150 and 200 degrees, the concrete stiffened so rapidly that it was impossible to finish it properly, and as a result the manufacturer who has been considering the making of equipment of this nature decided not to enter the business

DISCUSSION

ON

CONCRETE PAVEMENT MAINTENANCE

Mr H K Bishop, *U S Bureau of Public Roads* I have listened with a great deal of interest to Mr Trainor's paper and I was especially glad that he mentioned the desirability of giving particular attention to the aggregates in the frost area where the stresses and strains are different from those to which concrete is subjected in the southern states and in the arid western states One thing which he did not mention, but which I believe is important, is the question of subsoil conditions in the frost states Particular attention should be given in those states to the drainage and sub-surface conditions, and to the design of base courses Perhaps we have been confining our attention a little too closely to the design of pavements to withstand the stresses due to impact and giving too little consideration to the question of the subsoil conditions I would like to ask Mr Trainor, if I may, whether in the study that the Portland Cement Association is making any attempt will be made to tabulate or obtain information covering the cost of maintenance, and whether he anticipates that there may be some difficulty in such a study owing to the lack of uniformity in the way the state highway department keep their accounts.

MR TRAINOR Up to the present time we have not contemplated tabulating or making an investigation of maintenance costs and you touched on the reason why The various highway departments differ so widely in their methods of keeping maintenance costs that it did not appear to us to be possible, at this time, to make much out of the maintenance figures which are available This is a matter, however, that is not yet closed We have only had a year and a half of experience on this job and we are not sure that we have included all of the material that we should include, nor are we sure that we are not including some material which is of no value The party was taken out of the field and brought into Chicago in October after being in the field continuously since a year ago last June and they are now busily engaged in assembling, digesting and tabulating the data they have already taken Out of that study we will determine our plan of future action—as yet it is an open book