

gallon per inch of depth of loose aggregate on the road surface to be treated, the exact amount will vary with the grading and kind of aggregate and with the quality of bitumen and can not be definitely told except by actual experience

One should always be conservative in the amount of bitumen applied, permitting the road to be used by traffic and adding a small additional amount of bitumen where necessary in order to avoid raveling, rather than add too much in the beginning. It is frequently best to permit a small amount of raveling rather than put on an excess of bitumen as the raveling can always be taken care of by patching or applying a small additional amount of bituminous material. Such a surface is maintained by successive treatments as in maintaining a bituminous macadam or surface treated road.

These cheaper types of road surface do not produce a surface which will remain ideal without attention from time to time. It must be recognized when starting this class of work that attention to the maintenance of up-keep of the surface will be required and unless the work is undertaken with this requirement contemplated, it will not be a success. With proper attention given these cheaper types of surface they are frequently justified on the lighter traveled roads.

#### BERM MAINTENANCE

This subject is covered on pages 295-298 of the 1927 annual report of the Highway Research Board.

Grassed and ungrassed berms are discussed. Also, maintenance methods, maintenance costs and special features.

### MAINTENANCE COSTS AS AFFECTED BY TYPE OF PAVEMENT AND AMOUNT OF TRAFFIC

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The general belief is that the higher types of pavement are the most economical in maintenance costs and the maintenance records of the Pennsylvania Department of Highways appear to substantiate this belief.

The records of 1924 to 1927 inclusive show the following types, mileage, average annual cost of maintenance, and order in economy. The maintenance costs, as used here, include the items of grading, base, surface, drainage structures, roadside, traffic service, betterments,

overhead, surface treatment and resurfacing (snow removal not included)

	Mileage under mainte- nance in 1927	1924 to 1927 inclusive average annual costs of mainte- nance, surface treatment and resurfacing	Numerical order in economy
Reinforced Portland Cement Concrete	3,585	\$357 25	1
Sheet Asphalt on Portland Cement Con- crete Base	146	439 81	2
Plain Portland Cement Concrete	19	449 67	3
Earth and Cinders	3,584	493 76	4
Vitrified Brick on Portland Cement Con- crete Base	219	500 00	5
Stoned Road	215	533 23	6
Brick on Gravel or Stone Base	105	650 62	7
Bituminous Penetration on Broken Stone Base	212	650 85	8
Bituminous Penetration on Telford Base	161	677 77	9
Bituminous Concrete on Portland Cement Concrete Base	116	688 31	10
Gravel, Flint and Shale	251	801 51	11
Sheet Asphalt on Stone Base	50	838 19	12
Bituminous Concrete on Telford Base	117	885 57	13
Bituminous Surface Treated Macadam on Telford Base	644	1,024 15	14
Asphalt Block on Portland Cement Con- crete Base	10	1,197 88	15
Bituminous Concrete on Broken Stone Base	56	1,218 41	16
Bituminous Surface Treated Macadam on Broken Stone Base	1,527	1,504 92	17
Oilbound Broken Stone	867	2,671 08	18

In connection with these figures, it is necessary to bear in mind that the durable types, which show the lowest annual costs, are of comparatively recent construction, and their maintenance costs are likely to increase with their age, and furthermore, that maintenance costs for high type pavements are only a small part of the real annual costs. These points will receive attention later.

The inclusion of resurfacing with maintenance has a strong influence on relative costs. The apparent annual average cost shown for oilbound broken stone, for example, is a little more than forty per cent in resurfacing cost.

With the elimination of resurfacing charges, that is, based on surface costs of general repair and surface treatment only, the type, mileage under maintenance in 1927, annual average cost of surface maintenance, and numerical order in economy, are as follows:

Type	Mileage under maintenance in 1927	1924-1927 inclusive average annual costs of maintenance and surface treatment	Numerical order of economy	Order of economy previously shown including resurfacing
Reinforced Portland Cement Concrete	3,535	\$353 54	1	1
Sheet Asphalt on Portland Cement Concrete Base	146	439 81	2	2
Plain Portland Cement Concrete	19	449 67	3	3
Earth and Cinders	3,534	458 91	4	4
Stoned Road	215	493 85	5	6
Vitrified Brick on Portland Cement Concrete Base	219	500 00	6	5
Bituminous Concrete on Telford Base	117	590 19	7	13
Bituminous Penetration on Telford Base	161	611 04	8	9
Bituminous Penetration on Broken Stone Base	212	644 74	9	8
Brick on Gravel or Stone Base	105	650 62	10	7
Sheet Asphalt on Stone Base	50	664 04	11	12
Bituminous Concrete on Portland Cement Concrete Base	116	688 31	12	10
Gravel, Flint and Shale	251	726 71	13	11
Bituminous Concrete on Broken Stone Base	56	869 54	14	16
Bituminous Surface Treated Macadam on Telford Base	644	964 55	15	14
Asphalt Block on Portland Cement Concrete Base	10	1,197 88	16	15
Bituminous Surface Treated Macadam on Broken Stone Base	1,527	1,204 50	17	17
Oilbound Broken Stone	867	1,454 41	18	18

The elimination of the resurfacing charges affects each of the annual averages and occasions some readjustment in the order of economy in maintenance for the types, but naturally does not remove the durable types from the head of the list

With most types of pavement, we know that a certain amount of traffic spread over the surface is beneficial rather than injurious. For instance, impregnated wood block paving requires occasional compression to keep it from bulging, and bituminous binders, like rubber products, will retain "life" longer if they are subjected to a certain amount of kneading from time to time than if they are allowed to lie dormant.

Up to a certain point, which may differ for each type of pavement, traffic retards the deleterious effects of weather. Beyond that point, we would expect that traffic in increasing volume would damage the

**TABLE I**  
**COMMONWEALTH OF PENNSYLVANIA DEPARTMENT OF HIGHWAYS**  
**SUMMARY OF SURFACE MAINTENANCE COSTS INCLUDING GENERAL REPAIRS, SURFACE TREATMENT AND RESURFACING**  
**By Type of Pavement and Volume of Traffic for Year of 1923**

Type and Item	Traffic classification—daily average—all vehicles											Total	
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500		6000
Bituminous Surfaces Treated Macadam on Broken Stone Base													
Miles	706 631	886 603	378 547	241 805	74 236	62 831	8 402						
Cost per Car Mile	\$1,135.71	\$1,692.92	\$1,624.94	\$2,324.64	\$1,004.62	\$1,143.00	\$1,025.05						
Cost per Car Mile	0050	0036	0024	0023	0008	0008	0012						
Bituminous Surface Treated Macadam on Telford Base													
Miles	106 329	166 154	137 311	108 018	24 124	12 079	13 036	4 091					
Cost per Car Mile	\$1,043.40	\$958.57	\$1,254.41	\$1,730.91	\$1,244.95	\$1,394.06	\$637.22	\$1,735.88					
Cost per Car Mile	0043	0020	0015	0018	0011	0010	0003	0009					
Bituminous Concrete on Portland Cement Concrete Base													
Miles	23 804	7 177	27 395			10 183	1 482						
Cost per Car Mile	\$343.52	\$334.40	\$759.48			\$915.46	\$1,954.37						
Cost per Car Mile	0002	0001	0003			0005	0011						
Sheet Asphalt on Portland Cement Concrete Base													
Miles	15 199	49 354	35 234	3 207	4 152	1 326	1 053						
Cost per Car Mile	\$189.44	\$429.71	\$415.25	\$432.13	\$994.89	\$1,154.24	\$12,201.74						
Cost per Car Mile	0001	0003	0002	00003	0002	0004	0080						
Bituminous Concrete on Telford Base													
Miles	14 460	7 065	5 119	2 345	11 252	5 704							
Cost per Car Mile	\$418.80	\$1,299.79	\$406.45	\$2,255.03	\$504.69	\$2,259.17							
Cost per Car Mile	0005	0018	0005	0015	0001	0016							
Sheet Asphalt on Broken Stone Base													
Miles	604	1 099	38 813	8 600	7 879	6 991	4 630	492					
Cost per Car Mile	\$256.88	\$329.51	\$615.57	\$478.69	\$999.35	\$1,589.01	\$3,157.74	\$317.09					
Cost per Car Mile	0012	0007	0007	0001	0007	0006	0017	0002					
Reinforced Portland Cement Concrete													
Miles	162 254	395 380	377 949	159 466	44 370	29 306	2 101						
Cost per Car Mile	\$264.37	\$414.96	\$434.94	\$490.72	\$839.20	\$745.98	\$494.06						
Cost per Car Mile	0003	0003	0001	0002	0008	0002	0001						
Vitrified Brick on Portland Cement Concrete Base													
Miles	3 275	34 743	30 530	14 865	2 218	2 829	1 510						
Cost per Car Mile	\$490.20	\$567.87	\$482.72	\$2,181.99	\$485.14	\$567.82	\$1,610.60						
Cost per Car Mile	0018	0004	0002	0013	0002	0001	0008						
Grand Total													
Miles	2,520,020	3,015,511	1,375,709	665,770	179,277	167,110	5,636						
Cost per Car Mile	\$816.01	\$930.49	\$1,022.04	\$1,504.24	\$1,367.63	\$1,300.79	\$1,725.82	\$3,567.41					
Cost per Car Mile	0029	0016	0013	0014	0011	0008	0011	0021					

pavement rather than preserve it and evidence itself in maintenance cost increases approximately proportional, within the carrying capacity of the pavement, to the increases in traffic volume

Under test conditions, the determination of the points at which increasing traffic would enhance maintenance cost and the ratio of increasing cost to increasing volume of traffic would be difficult. With selected subgrade conditions, close uniformity of pavement construction and maintenance, fixed wheel load, constant speed, and absence of variation in climatic conditions, we might expect a single test to yield closely approximate determinations, and several tests to warrant reliable conclusions, but pavements under actual traffic are affected by so many variable factors that any figures representing small mileage must be viewed with suspicion and considered with caution.

If care is used to avoid the selection of accidental figures, and always recognizing the fact that an apparent corroboration may be merely a coincidence, we can get from the Pennsylvania record some interesting evidence of maintenance cost varying with the volume of traffic.

The particular record used is the summary of surface maintenance cost, including general repairs, surface treatment, and resurfacing for the year 1923. The types shown are the principal types of surface in the state and the figures shown represent the total mileage of those types under maintenance and the total cost of maintenance. The traffic figures are from 1923 and 1924 traffic census counts with some interpolations.

Bituminous surface treated macadam on broken stone base is shown as varying from \$914.00 per mile and \$0.0050 per car mile for 500 traffic to \$1,620.23 per mile and \$0.0012 per car mile for 5,500 traffic. The cost per mile indicates a fairly consistent increase with the traffic while the car mile cost decreases.

Bituminous surface treated macadam on telford base shows slightly lower costs ranging from \$799.65 per mile and \$0.0043 per car mile for 500 traffic to \$1,336.15 per mile and \$0.0009 per car mile for 4,000 traffic. The less than one-third of a mile classified as 3,500 traffic is too short a length of road to be considered as furnishing any average figures. This type also shows a fairly consistent increase in maintenance cost with increase in traffic, and an almost regular decrease in car mile cost.

Bituminous concrete on concrete base shows \$92.68 per mile and \$0.0002 per car mile for 1,000 traffic and an increase to \$1,439.85 per mile and \$0.0011 per car mile for 3,500 traffic. The appearance of this line of figures is due to the fact that the mileage classified as 1,000, 1,500 and 2,000 did not receive surface treatment or any resurfacing in the year 1923.

Passing on to the high type of surface, we find that reinforced con-

crete shows a range of from \$71 44 per mile and \$0 0003 per car mile for 500 traffic to \$125 84 per mile and \$0 0001 per car mile for 3,500 traffic, and does not give any reliable indication of increasing maintenance cost with increasing volume of traffic. As according to expectations, volume of traffic does not materially affect the maintenance cost of this type of pavement, at least in its early years of age.

The maintenance records of reinforced Portland cement concrete surfaces built from 1915 to 1920, with the item of shoulder maintenance carried as distinct from the general surface charges appear, as follows, when the tabulation is by year of maintenance (age of pavement)

Year of maintenance	Miles under maintenance	Average maintenance cost per mile		
		Surface	Shoulders	Surface and shoulders
First	285 93	\$46 14	\$94 70	\$140 84
Second	283 69	64 37	68 93	133 30
Third	283 69	108 04	132 53	240 57
Fourth	283 69	153 27	139 67	292 94
Fifth	281 41	98 62	102 86	201 48
Sixth	281 41	89 54	84 99	174 53
Seventh	281 41	134 49	95 99	230 48
Eighth	59 73	213 18	128 74	341 92
Ninth	12 69	177 16	54 86	232 02
Tenth	5 70	363 77	80 06	443 83
Eleventh	5 70	300 42	68 78	369 20
Annual average (not weighted)		\$159 00	\$95 65	\$254 65

These figures apply to all of the reinforced concrete pavement that we laid from 1915 to 1920, inclusive, and include several different cross sections and different systems of reinforcing and the pavements are carrying a wide range of traffic.

A single definite type, eighteen feet wide, six inches thick at edges and eight inches thick at center, on flat subgrade, with twenty-five pounds of steel to the hundred square feet, shows maintenance costs classified by volume of traffic.

These extended figures for maintenance of reinforced concrete show that we must expect some cumulative effect of age and traffic but that until the pavements have been under traffic for several more years we cannot forecast their maintenance many years with any great degree of accuracy.

As previously mentioned, and particularly for high type pavements that are built with bond funds, it is necessary to consider depreciation and interest charges together with maintenance costs. In practice the sum of surface maintenance charges and depreciation and interest for different types under similar conditions will be very approximately

TABLE II

COMMONWEALTH OF PENNSYLVANIA, DEPARTMENT OF HIGHWAYS  
 MAINTENANCE COSTS PER MILE—REINFORCED CONCRETE ROADS  
 TRAFFIC ANNUAL DAILY AVERAGE INCLUDING PASSENGER CARS AND MOTOR TRUCKS  
 YEAR PROJECTS COMPLETED 1920\*

12-6-8-6

Year of maintenance	28 12 miles			56 22 miles			29 67 miles			19 91 miles			4 90 miles		
	Traffic 500 (0-750)		Total surface and shoulders	Traffic 1000 (751-1250)		Total surface and shoulders	Traffic 1500 (1251-1750)		Total surface and shoulders	Traffic 2000 (1751-2250)		Total surface and shoulders	Traffic 2500 (2251-2750)		Total surface and shoulders
	Surface	Shoulders		Surface	Shoulders		Surface	Shoulders		Surface	Shoulders		Surface	Shoulders	
First†	\$34 13	\$94 33	\$128 46	\$54 99	\$85 53	\$150 52	\$36 68	\$37 94	\$74 62	\$76 48	\$117 84	\$194 32	\$12 55	\$198 52	\$212 07
Second	42 68	90 31	132 99	95 99	61 08	157 07	84 33	48 57	132 50	74 20	139 77	213 97	29 78	44 44	74 22
Third	66 29	209 01	275 30	95 58	207 80	303 38	273 94	60 47	334 41	211 31	268 25	479 56	59 96	121 15	181 11
Fourth	105 69	69 34	175 03	117 37	96 68	214 05	85 52	133 85	219 37	134 36	232 81	367 17	88 93	137 43	226 36
Fifth	63 13	102 52	165 65	67 29	70 17	137 46	102 90	78 40	181 30	87 04	128 45	215 49	53 65	40 92	94 87
Sixth	58 76	97 74	156 50	81 96	55 00	136 96	51 18	88 28	139 46	98 56	127 44	228 00	211 46	17 49	228 95
Seventh	96 14	90 74	186 88	81 98	75 49	157 47	80 29	93 38	173 67	65 99	155 51	221 50	258 62	104 62	363 24
Average Total Expenditures Per Mile	466 82	753 99	1 220 81	595 16	661 75	1 256 91	714 84	540 89	1 255 73	747 94	1 170 07	1 918 01	715 25	665 57	1 380 82
Average Annual Cost Per Mile	66 69	107 71	174 40	85 02	94 53	179 56	102 12	77 27	179 39	106 85	167 15	274 00	107 18	95 08	197 26
Year of maintenance	5 45 miles			1 53 miles			0 50 miles			146 30 miles					
	Traffic 3000 (2751-3250)		Total surface and shoulders	Traffic 3500 (3251-3750)		Total surface and shoulders	Traffic 60000 (5751-6250)		Total surface and shoulders	Average totals		Total surface and shoulders			
	Surface	Shoulders		Surface	Shoulders		Surface	Shoulders		Surface	Shoulders				
First†	\$139 81	\$211 02	\$350 83	\$28 10		\$28 10		No cost reported		\$51 46	\$93 12	\$144 53			
Second	67 50	197 06	264 56	7 90		31 00		No cost reported		75 89	78 77	154 66			
Third	92 79	200 55	293 34			\$23 10		No cost reported		139 24	180 32	319 56			
Fourth	215 47	124 43	339 90			No cost reported		No cost reported		112 19	118 74	230 93			
Fifth	87 99	95 54	183 53	13 48	18 48	31 96		No cost reported		70 92	85 01	161 93			
Sixth	72 94	44 13	117 07	107 67	2 61	110 28		No cost reported		85 49	79 84	165 33			
Seventh	62 32	210 04	272 36	637 14	179 08	816 22		\$714 60	\$168 00	88 86	98 41	187 27			
Average Total Expenditures Per Mile	738 82	1 082 77	1 821 59	806 08	254 04	1 060 13		1 449 92	228 30	630 05	734 21	1 364 26			
Average Annual Cost Per Mile	105 55	154 68	260 23	115 15	36 29	151 44		207 13	32 61	90 00	104 89	194 89			

\* Each project is entered according to the year it was entirely completed

† First year maintenance is the first calendar year after entire project was completed Any maintenance in the years of completion is added to the first calendar year maintenance





TABLE III—Continued

Commonwealth of Pennsylvania Department of Highways		Traffic Section—Annual Charges Pavement Only (Base and Surface)		Legislative Route 142					
County	Township	Mile to Mile	Station to Station	Traffic Section No	Miles				
	<i>Chester</i>	<i>Cata</i>	<i>17 50—22 00</i>	7	4 50				
Supt. Dist. No.	Trucks	Current Value	Depreciation and Interest	Genl. Maint.	Surface Treatment	Total Maint.	Total	Av. Cost per Mile	Ad-justed
8-3	Total	Base	Surface	Total	Base	Surface	Av. Cost per Mile	Actual	cents
12	305	30	19,282	19,312	5	408	2,306	2,306	4599
13	437			2,989	5	672	2,817	5,811	8094
14	617			2,989	5	911	3,410	6,404	6319
15	746			2,989	5	1,132	10,180	13,174	1 0750
16	915			2,989	5	2,790	5,841	8,535	5878
17	1,082			2,989	5	3,224	6,141	9,135	5140
18	1,308			2,989	5	2,044	5,118	8,112	3776
19	1,574	12	5,533	2,994	5	2,216	4,851	7,845	3034
20	2,311	12	2,247	2,989	5	4,467	7,670	12,699	3346
21	2,498			5,020	9	7,091	10,564	13,804	3364
22	2,623			3,240	10	2,635	6,072	9,324	2164
23	2,870			10,791	12	2,286	286	11,077	2350
24	3,065			10,791	12	1,441	1,446	12,237	2430

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 poor 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