In Highway Research Record Number 177, on page 210, the followir sentence should be added at the end of the third paragraph:

"The research was sponsored by Douglas County, Nebraska, Willia Green, County Surveyor."

Retention of Density in Loess Subgrades and Soil-Aggregate Base Mixtures

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•THE strength of flexible pavements depends to a large extent on the strength of the subgrade and base, and the strength of these two layer components depends primarily on their density. The density therefore is of prime importance in the performance of flexible pavements. While the importance of density is generally acknowledged, there are engineers who say that the compaction of the subgrades and water-bound bases is a waste of money since eventually they will de-densify and revert to a loose state such as exists in uncompacted soils.

To our knowledge, there is a dearth of published information on the retention of density in compacted subgrades and bases. No doubt information along this line is available and perhaps some will be furnished in the discussion of the paper.

Our principal purpose is to present data on the retention of density in subgrades composed of loessial soils and in bases composed of aggregates and loess binder. However, since moisture is related to density, moisture contents are included in the research and will be reported also. The objective was accomplished by comparing density and moisture content tests obtained during construction on several projects with similar tests made a number of years after construction.

GENERAL DATA

The research included the sampling and testing of subgrades and bases ranging in age from 4 to 18 years. Eleven projects were investigated, each 1 mile in length. Generally, five locations were tested per mile. The projects are representative of about 200 miles of flexible pavement constructed on mail routes since 1948 in Douglas County, Nebraska.

The paving was done by the stage construction method. Initially, a 20-ft pavement was constructed consisting of a 6-in. compacted subgrade, a 4-in. compacted soil-aggregate base and a prime and double armor coat. Also, a 4 by 12-in. curb, the top of which was even with the top of the base, was constructed along each edge of the subgrade and base. Incidentally, the curb was used to provide lateral support and to prevent progressive disintegration at the edges of the base due to tire traffic.

The second stage consisted of the application of a 2-in. asphaltic concrete mat. The length of time elapsing between stages depended on the traffic count, the service behavior of the double armor, and other factors, such as political influence. Table 1 gives the years in which the first and second stages were constructed on the various projects.

Table 1 also contains the location of the projects investigated, the prevailing traffic counts, the condition of the road surface and the environment. The environment in this case refers to the type of terrain and drainage. Note that with the exception of project 2, all the counts are low. The distress noted in some of the projects refers to the breakup and disintegration of the surface. No tests were made on these areas because the distress was manifestly due to the weakness in the basement soils.

Paper sponsored by Committee on Compaction and presented at the 46th Annual Meeting.

TABLE 1

PROJECT LOCATIONS AND PERTINENT DATA

Project No.	Road and Location	Environment	Surface Condition	Mixed Daily Traffic Count	Date of Construction	
					1st Stage	2nd Stage
1	Road 60 between roads 5 and 1	Hilly, well drained	Good, one distressed area	276	1948	1953
2	Road 33 between roads 38 and 42	Hilly, well drained	Good	3072	1948	1952
3	Road 82 between roads 41 and 45	High ground, ridge, well drained	Good	431	1948	1955
4	Road 5 between roads 16 and 20	Valley, parallels creek, drainage fair	Good, several distressed areas	496	1950	1954
5	Road 16 between roads 5 and 1	North half, valley, fair drainage; South half, hills, good drainage	Good, one distressed area	776	1950	1957
6	Road 41 between roads 56 and 60	Hilly, well drained	Good, several distressed areas	668	1950	1953
7	Road 21 between roads 46 and 42	Hilly, well drained	Good	250	1951	1956
8	Road 15 between roads 9 and 32	Partly hilly; partly valley	Good	188	1953	1956
9	Road 22 between roads 5 and 1	Valley, parallels creek, fair drainage	Good	273	1954	1961
10	Road 80 between roads 25 and 29	Partly hilly; partly valley, good drainage	Good	227	1957	1965
11	Road 44 between roads 29 and 33	Hilly, well drained	Good	625	1962	1962

Data on Subgrades and Base Mixtures

The subgrade soils consist principally of Peoria loess. In its unadulterated state, this soil passes a No. 200 sieve, contains 10 to 20 percent clay and 80 to 90 percent silt, has a liquid limit of 30 to 40 and a plasticity index of 10 to 15, a maximum density of 104 lb/cu ft dry, and an optimum moisture of 18 percent as determined by ASTM D698-65T.

During construction, the upper 6 in. of the subgrades were compacted to at least 100 percent of maximum density. Because the roads had been graveled prior to the construction of the first stage, some gravel was included in most of the test samples. To compensate for the gravel content in computing maximum density, a formula was developed. Experimentally, the formula is $(A \times 0.364) + B =$ maximum density, in which A is the percentage of gravel and B, the maximum density of the unadulterated soil.

The base mixture used on all the projects except 6 and 11 consisted of 60 percent crusher-run limestone, 35 percent sands and gravel and 5 percent loess soil. This mixture had a maximum density of 143 lb/cu ft dry and an optimum moisture of 5.5 percent. The minus 40 material had a liquid limit of 16 to 22 and a plasticity index of 2 to 7.

The base for project 6 consisted of 90 percent sand-gravel and 10 percent loess soil. The mixture had a maximum density of 138 lb/cu ft dry and an optimum moisture of 6

TABLE 2

GRADATION OF BASE MIXTURES

Project	Percent Retained On:							
	1¼ In. Sieve	¾ In. Sieve	½ In. Sieve	⅜ In. Sieve	No. 4 Sieve	No. 10 Sieve	No. 40 Sieve	No. 200 Sieve
6	—	—	0.0	2.0	11.0	35.0	65.0	88.0
11	—	—	0.0	4.0	19.0	55.0	72.0	93.0
All others	0.0	5.0	—	23.0	37.0	52.0	72.0	85.0

TABLE 3

1966 FIELD DATA, SUBGRADE

Project No.	Test No.	Maximum Laboratory Density (lb/cu ft)	Density		Moisture		
			Weight per Cu Ft (lb)	Percent of Max. Lab. Density	Entire Sample (%)	Gravel-Free Soil	
						Percent of Sample	Percent of Optimum
1	1	105.8	97.9	92.6	24.5	26.0	144.0*
	2	104.8	105.3	100.5*	16.8	17.2	95.5*
	4	104.4	96.6	92.6	21.2	21.4	118.9
	5	108.0	97.3	90.0	20.8	23.4	130.0
	6	104.0	97.3	93.4	19.5	19.5	108.3
2	1	104.0	103.3	99.3	17.2	17.2	95.5
	2	104.0	106.5	102.4	11.6	11.6	64.4*
	3	104.0	97.0	93.3*	25.3	25.3	140.5*
	4	110.6	117.0	105.7	12.6	15.6	86.7
	5	104.0	101.5	97.6	22.1	22.1	122.7
3	1	106.6	106.0	99.5	17.4	18.7	103.8
	2	104.8	106.9	102.0	17.4	17.9	99.5
	3	104.0	95.5	91.8*	24.7*	24.7*	137.2*
	4	107.1	106.4	99.3	18.5	20.2	112.2
	5	104.7	103.5	98.9	19.4	19.8	110.0
4	1	111.2	113.1	101.8	13.5	17.0	94.0
	3	105.8	108.9	101.7	16.3	17.2	95.0
	4	120.1	120.1	97.6	8.5	17.7	98.0
	5	117.5	117.5	103.8	10.6	15.1	84.0
5	1	104.8	106.1	101.2	16.3	16.7	92.8
	2	105.3	95.3	90.4	23.0	23.8	132.2*
	3	108.1	105.7	97.8	15.1	17.0	94.4
	4	110.4	109.0	98.6	12.5	15.2	84.4
	5	105.0	101.1	96.3	19.1	19.6	108.8
6	1	107.0	112.7	105.4	15.1	18.5	102.7
	2	107.7	109.4	101.5	17.0	18.9	105.0
	3	105.1	109.5	104.1	19.3	19.9	110.5
	4	116.7	119.3	102.1	12.4	19.1	106.1
	5	107.6	109.3	101.5	17.0	18.9	105.0
7	4	105.0	104.3	99.4	21.2	21.9	121.6
	5	108.6	102.6	99.4	20.5	23.5	130.6
	6	105.8	110.3	104.2*	16.8	17.7	98.4*
	7	104.0	100.6	96.6	22.9	22.9	127.2
	8	104.0	99.5	95.6	22.4	22.4	124.4
8	1	104.0	102.0	98.1	22.4	22.4	124.4
	2	104.0	104.1	100.0	22.4	22.4	124.4
	3	104.0	96.3	92.6	24.2	24.2	134.4
	4	104.0	100.0	96.2	23.0	23.0	127.7
	5	104.0	96.0	92.2	25.5	25.5	141.6
9	2	106.3	106.0	100.0	15.6	16.7	92.8
	3	104.9	104.0	99.2	20.0	20.5	113.8
	4	105.5	109.1	103.3	17.0	17.7	98.4
	5	105.9	107.2	101.3	17.7	18.7	103.8
	6	104.0	93.5	89.9*	24.4	24.4	135.5*
10	2	106.0	99.9	94.2	17.7	18.7	103.9
	3	109.4	106.6	97.5	16.3	19.1	106.1
	5	104.6	102.0	97.5	18.1	18.4	102.1
	6	109.2	111.5	102.0	15.7	18.5	102.7
	7	104.0	102.1	98.2	19.6	19.6	109.9
11	1	104.0	105.4	100.3	18.1	18.1	100.0
	2	104.0	100.0	96.2	22.8	22.8	126.6
	3	110.1	114.8	104.2	14.6	17.5	97.2
	4	104.0	104.0	100.0	21.6	21.6	120.0
	5	104.0	107.4	103.2	18.9	18.9	105.0

*This value not used in computing averages shown in summary, Table 7.

percent. The minus 40 material had a liquid limit of about 16 and a plasticity index of about 4.

Project 11 was included for the purpose of showing the behavior of an asphalt-treated base. The aggregates in the base were sands and gravel whose minus 40 material was nonplastic. The total mixture contained 3 percent bitumen by weight in the form of emulsion, had a maximum density of 135.7 lb/cu ft, aggregate and bitumen, and an optimum moisture content of 5.2 percent. Typical gradations of each of the three types of mixture are given in Table 2.

SAMPLING AND TESTING PROCEDURES

The sampling and testing during construction was done by standard methods as each layer component was finished by the contractors. The procedure used in April 1966 was as follows: The asphalt surface was removed with a 10-in. diamond-core bit. The base was then sampled and tested by the sand method, ASTM D 1556-64, and then the subgrade was tested by the use of a 3 by 6-in. calibrated tube which was driven into the soil.

The moisture content of both the subgrade and base was determined in the laboratory by the oven method. In order to compensate for the gravel on the maximum density as explained earlier, the gravel content was determined on each subgrade sample by a washing process.

Tabulation of the Test Results Obtained in 1966

The results of the subgrade tests are given in Table 3. This table contains weight per cubic foot, maximum density, relative density and moisture content in the entire sample as well as in the gravel-free soil. The moisture content in the gravel-free soil is also expressed as a percentage of optimum.

The test results obtained for the base are shown in Table 4. This table includes weight per cubic foot, percent of relative density, and moisture content expressed as a percentage of the sample and also as a percentage of optimum moisture.

Tabulation of Test Results Obtained Initially

The test data obtained during construction are given in Tables 5 and 6. Table 5 gives the subgrade tests and 6, the base tests. The type of data in these two tables is the same as given in Tables 3 and 4.

As far as the moisture contents are concerned in the initial set of tests, it must be remembered that the moisture content is that existing when the density test was made. The moisture content depends on how much time elapsed between the time the contractor completed his work and the time the inspector made the test. Furthermore, the moisture contents of the subgrade were no doubt lower than reported when the base was added, and the base moistures lower than reported when the armor coats were added. The intital moisture contents are not of any great significance and are included for the purpose of showing what they were at some time during construction.

Summary of Initial and 1966 Tests

A summary of the test results obtained initially and in April 1966 is given in Table 7. The summary may be used to show a comparison of densities and moisture contents. The individual figures, with few exceptions, are the average of five tests. In computing their averages, individual tests which are manifestly out of line were not inlcuded, as indicated by an asterisk in Tables 3 and 4.

DISCUSSION

A comparison of the data obtained in April 1966 with those obtained during construction substantiates the following:

1. As far as the subgrade density tests are concerned, eight of the projects show densities of 97 to 103 percent of maximum density. This compares well with the intital

TABLE 4

1966 FIELD DATA, BASE

Project No.	Test No.	Density: Weight per Cu Ft (lb)	Density: Percent of Max. Lab. Density	Moisture: Percent of Sample	Moisture: Percent of Optimum Moisture
1	1	145.2	101.5	4.7	85
	2	153.3	107.2*	3.6	65
	3	145.0	101.5	3.8	69
	4	149.2	104.3	3.1	56
	5	149.9	104.8	3.8	59
2	1	146.0	102.0	2.8	51
	2	157.0	109.7	2.4	49
	3	144.3	100.8*	4.4	80
	4	153.1	107.0	3.3	60
	5	152.3	106.5	3.1	56
3	1	145.9	102.0	3.3	60
	3	148.6	104.0	3.3	60
	4	143.6	100.5	5.0	91
	5	145.1	101.4	4.4	80
4	1	147.5	103.1	3.7	67
	2	148.2	103.6	3.0	55
	3	148.4	103.7	3.6	65
	4	145.9	102.0	3.5	64
	5	143.1	100.0	3.9	71
5	1	144.0	100.7	4.5	82
	2	145.4	101.7	5.1	93
	3	145.5	101.7	3.4	62
	4	147.7	103.3	3.6	65
	5	141.1	98.7	3.8	69
6	1	145.6	105.5	3.8	63
	2	145.2	105.2	6.1	102
	3	145.6	105.5	4.8	80
	4	136.9	99.3*	4.8	80
	5	141.2	102.6	3.8	63
7	1	139.2	97.4*	4.3	78
	2	147.9	103.4	4.8	87
	3	149.8	104.7	3.7	67
	4	160.6	113.0*	3.7	67
	5	152.9	107.0	4.0	73
9	1	148.0	103.5	5.7	104
	2	142.2	99.5	6.2	113
	3	142.5	99.7	5.7	104
	4	154.2	107.6*	4.7	85
	5	144.0	100.6	5.9	107
10	1	148.8	104.0	3.8	69
	2	143.3	100.2	4.4	80
	3	147.7	103.1	4.0	73
	4	148.7	103.8	3.0	55
	5	144.9	101.2	3.8	69
11	1	143.4	105.5	0.7	13
	2	141.6	104.2	1.3	25
	3	142.8	105.0	0.7	13
	4	142.6	104.9	0.7	13
	5	139.0	102.3	0.7	13

Note: Base samples were not taken on project 8.

*This value not included in the averages shown in summary, Table 7.

TABLE 5

INITIAL DATA, SUBGRADE

Project No.	Test No.	Maximum Laboratory Density (lb/cu ft)	Density		Moisture		
			Weight per Cu Ft (lb)	Percent of Max. Lab. Density	Entire Sample (%)	Gravel-Free Soil	
						Percent of Sample	Percent of Optimum
1	1	104.0	103.5	99.6	16.3	16.3	90.0
	2	118.0	118.0	100.0	11.2	18.2	100.0
	3	108.5	108.6	100.0	11.0	14.7	82.0
	5	104.0	104.5	100.5	11.0	11.0	61.0
	6	104.0	106.0	101.8	15.2	15.2	84.0
2	1	119.6	119.6	100.0	7.2	12.6	70.0
	2	107.2	109.7	102.3	14.0	16.6	92.0
	3	118.0	119.2	101.0	11.3	13.2	74.0
	4	104.0	105.1	101.0	17.1	17.1	95.0
	5	104.0	104.4	100.3	16.5	16.5	92.0
3	1	110.5	111.6	101.0	12.1	18.0	100.0
	2	104.0	105.8	101.7	16.7	16.7	93.0
	3	104.0	104.2	100.1	17.6	17.6	98.0
	4	104.0	103.0	99.0	20.0	20.0	111.0
	5	106.0	106.3	100.2	18.3	19.9	111.0
4	1	104.0	106.7	102.6	16.9	17.2	94.0
	2	109.8	113.9	103.6	13.3	16.0	88.0
	3	105.9	115.3	108.9	13.6	5.0	27.5
	4	109.1	112.8	103.5	15.4	13.5	74.3
	5	116.7	119.1	102.1	10.9	35.0	192.6
5	1	112.0	113.4	101.3	12.2	15.7	87.0
	2	104.0	106.5	102.4	17.3	17.3	96.0
	3	107.3	109.6	102.1	18.2	20.0	111.0
	4	105.8	111.0	104.8	15.5	16.3	91.0
	5	109.5	109.7	100.1	14.3	16.8	93.0
6	1	104.0	104.1	100.0	18.8	18.8	104.0
	2	109.0	108.0	99.1	16.1	18.7	104.0
	3	104.0	105.0	100.8	15.3	15.3	85.0
	4	106.4	107.5	101.0	13.9	13.9	78.0
	5	104.0	105.0	100.8	16.5	16.5	92.0
7	4	112.0	109.3	97.7	15.7	20.1	112.0
	5	120.1	119.1	99.2	9.9	21.0	114.0
	6	108.0	108.0	100.0	17.6	19.8	110.0
	7	120.5	118.9	98.8	10.5	21.0	114.0
	8	118.8	115.4	97.2	11.9	20.2	112.0
8	1	104.0	105.5	101.4	16.8	16.8	94.0
	2	111.2	112.2	100.8	17.8	17.8	99.0
	3	111.2	110.0	99.7	16.7	16.7	93.0
	4	104.0	105.0	101.0	17.5	17.5	98.0
	5	104.0	105.0	101.0	16.5	16.5	92.0
9	2	113.1	114.4	101.0	16.3	20.9	116.0
	3	108.0	108.0	100.0	15.4	16.7	93.0
	4	108.7	109.2	100.5	16.7	18.5	103.0
	5	109.0	109.8	101.0	19.5	21.9	122.0
	6	109.0	109.2	100.0	16.8	19.9	110.0
10	2	117.5	117.6	100.0	9.7	15.5	86.0
	3	129.1	129.1	100.0	5.7	18.4	102.0
	5	133.5	134.0	100.3	5.3	19.5	108.0
	6	119.0	125.0	105.0	7.5	17.9	100.0
	7	114.9	115.2	100.2	10.6	15.4	86.0
11	1	111.6	118.5	106.0	13.7	17.3	96.0
	2	131.8	135.6	103.0	4.5	18.7	104.0
	3	122.6	128.5	104.7	8.3	16.5	92.0
	4	115.9	116.1	100.2	10.8	15.9	89.0
	5	118.0	119.1	100.8	6.8	11.0	61.0

TABLE 6

INITIAL DATA, BASE

Project No.	Test No.	Density: Weight per Cu Ft (lb)	Density: Percent of Max. Lab. Density	Moisture: Percent of Sample	Moisture: Percent of Optimum Moisture
1	1	148.0	103.4	2.6	47
	2	141.6	99.1	2.1	38
	3	144.2	100.9	3.0	55
2	1	142.3	99.6	2.1	38
	2	148.0	103.4	2.6	47
	3	144.1	100.8	2.0	36
	4	143.5	100.3	2.0	36
	5	144.1	100.8	2.1	38
3	1	142.8	99.9	3.6	65
	2	144.9	101.2	2.9	53
	3	142.8	99.9	3.2	58
	4	144.3	101.0	3.2	58
	5	141.3	98.8	3.1	56
4	1	144.0	100.6	3.7	59
	2	150.5	105.2	3.0	55
	3	145.2	101.7	3.6	65
	4	143.0	100.0	3.5	64
	5	143.3	100.2	3.9	71
5	1	144.3	101.0	3.0	55
	2	143.8	100.5	2.6	47
	3	143.0	100.0	2.8	51
	4	147.5	103.2	2.7	49
	5	143.0	100.0	3.1	56
6	1	137.3	99.3	3.0	50
	2	135.8	98.2	3.6	60
	3	136.0	98.6	2.8	47
	4	137.9	99.9	3.1	52
	5	137.3	99.3	2.7	45
7	1	143.0	100.0	2.3	42
	2	142.2	99.5	2.5	45
	3	143.9	100.7	2.1	38
	4	147.7	103.3	2.0	36
	5	142.8	99.7	2.6	47
9	1	139.0	97.3	4.9	89
	2	137.1	99.2	4.1	75
	3	143.9	100.7	5.3	96
	4	143.0	100.0	4.7	86
	5	143.7	100.6	5.7	104
10	1	146.5	102.6	2.9	53
	2	149.2	104.3	1.9	35
	3	148.7	104.0	2.5	45
	4	155.1	108.5	2.9	53
	5	148.7	104.0	1.8	33
11	1	135.7	100.0	2.7	49
	2	139.2	102.8	3.3	60
	3	138.5	102.2	2.5	46
	4	138.4	102.1	2.7	49
	5	140.3	103.5	2.5	46

Note: Base samples were not taken on project 8.

TABLE 7

SUMMARY OF INITIAL AND 1966 TESTS

Project No.	Moisture (%)		Density (% of Max. Lab. Density)		Condition of Surface	Traffic Count
	Initial	1966	Initial	1966		
			Subgrade			
1	89	119	100	92	Good, one distressed area	276
2	85	102	100	101	Good	3072
3	103	106	100	100	Good	431
4	91	93	103	101	Good, several distressed areas	496
5	92	106	100	97	Good, one distressed area	776
6	93	95	101	103	Good, several distressed areas	668
7	112	126	101	96	Good	250
8	95	124	100	96	Good	188
9	109	102	100	101	Good	273
10	94	105	100	98	Good	227
11	95	106	100	101	Good	625
			Base			
1	47	67	101	103		
2	39	54	101	106		
3	58	73	100	102		
4	63	65	101	102		
5	52	74	101	101		
6	51	72	99	104		
7	42	74	101	105		
9	90	86	100	101		
10	44	69	104	102		
11	50	16	102	104		

density. However, in two of the projects, the density now is only 96 percent of maximum and one of the projects shows only 92 percent of maximum density.

2. All the subgrade moisture contents in 1966 are higher than they were initially. However, the moisture content in eight projects does not exceed 106 percent of optimum. In projects 1, 7 and 8, the moisture content ranges from 119 to 126 percent of optimum.

In connection with these observations on moisture contents, although low average moisture contents are shown in projects 2, 3, 4, 9 and 11, each of the projects mentioned contains one test in which the moisture was quite high. Some of the locations are in low filled areas, but some are in hilly areas. We cannot account for the high results in the latter.

3. The 1966 tests on the base show that the moisture content has not reached optimum in any of the projects and that the density has increased in 10 of the 11 projects. The average moisture content is 70 percent of optimum and the average density is 103 percent of maximum.

The moisture content of the base in project 11 deserves special mention. Note in the 1966 survey that the mixture on this project, which is an asphalt coated aggregate, is only 16 percent of optimum, whereas it was 50 percent initially. The only plausible explanation we can offer is to assume that this base dried out before the asphalt mat was applied and that it did not absorb any moisture subsequently.

4. There appears to be no relationship between age and retention of density in the subgrade. For instance, projects 7 and 8, constructed in 1951 and 1953 respectively, have lower densities than projects 1 and 2, constructed in 1948.

5. There appears to be no relationship between subgrade density and traffic count. This is no doubt due to the fact that with one exception the traffic counts are low. Project 2, with a traffic count of about 3,000, is in excellent condition. This indicates that 4 in. of base and 2 in. of asphaltic concrete can handle considerable traffic.

6. There appears to be no relationship between density in the subgrade and surface condition. The surface condition is good on all projects. The distress which exists on projects 4 and 6 is manifestly due to improper fills or inherently weak basement soils.

CONCULSIONS

This research seems to warrant two general conclusions. First, compacted soil-aggregate bases retain their initial densities very well even if the underlying subgrade becomes quite wet. Second, compacted loessial soil subgrades in flexible pavements retain densities equal to or in the vicinity of maximum in 91 percent of the projects investigated.

The results of this investigation should also serve to dispel the fears of those who are skeptical about the permanency of compaction of soils and soil-aggregate mixtures.