BULLETIN 330 JANUARY, 1928

COLORADO PAVEMENT AND SUBGRADE STUDIES

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COLORADO PAVEMENT AND SUBGRADE STUDIES

By O. V. Adams and J. G. Rose*

Early in 1925, an arrangement was entered into by the Colorado State Highway Department, the District Office of the U. S. Bureau of Public Roads, and the Road Materials Laboratory of the Colorado Experiment Station for a co-operative pavement and subgrade soil investigation in Colorado.

Under this arrangement, the Bureau of Public Roads furnished the part-time services of one engineer and gave the State Highway Department one three-ton truck upon which to mount the core drill outfit. The State Highway Department furnished the core drill, paid the salary and expense of the core drill operator and one-half of the laboratory salary expense exclusive of that of the testing engineer; the Road Materials Laboratory paid the salary of the testing engineer, one-half of all other laboratory salaries, the salary and expenses of one man on the field party and provided all necessary laboratory equipment and supplies.

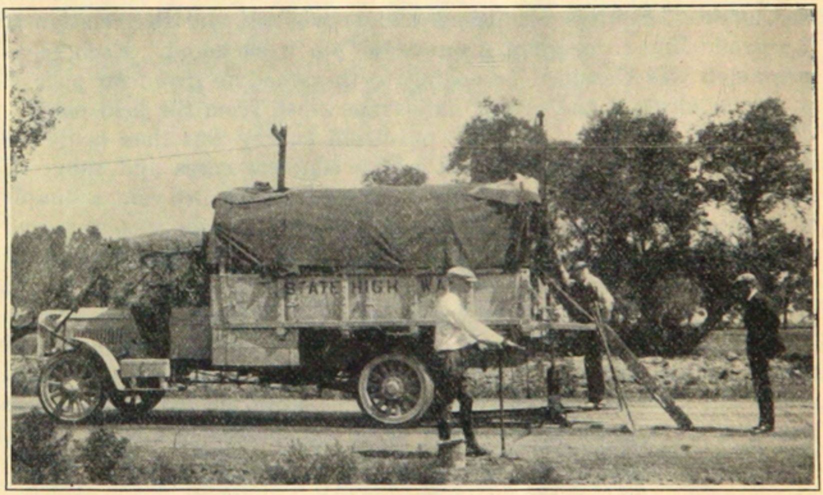


Figure 1.—Core drill outfit drilling core and sampling subgrade soil.

The field party commenced work about June 15, 1925, and, during both 1925 and 1926, continued work until cold weather made field operations impracticable. The investigations included pavements laid during the period of 1916 to 1926.

The entire study was based on a careful pavement survey. A record of all cracks, faults, wear and other defects in the pavement

* Deceased before this bulletin went to press.

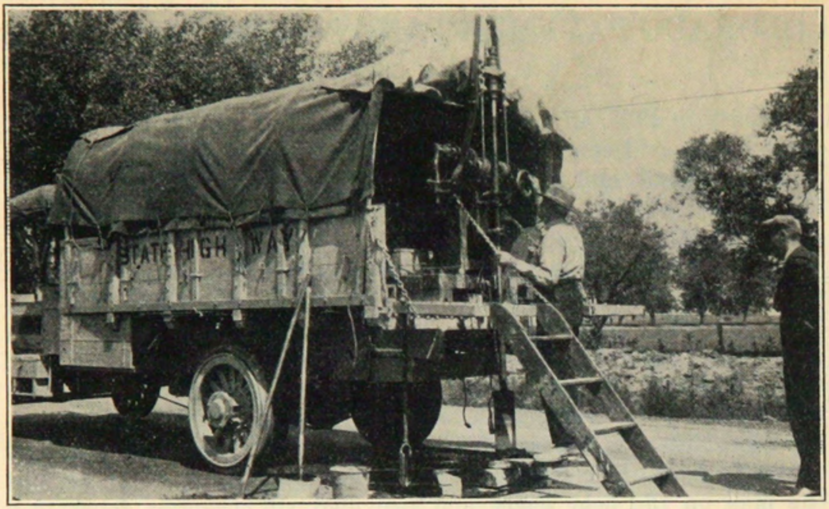


Figure 2.—Core drill in operation.

was made. Drainage conditions and provisions, and the relation of the grade line to original ground surface were noted. Each pavement slab was classified according to the schedule given on page 6. A sample sheet of the survey data transcribed from the field notes is shown in Fig. 3, page 8. This pavement survey was then made the basis for locating the points at which concrete cores and subgrade samples were to be taken. After each core was drilled and a sample of subgrade soil taken, the thickness of the pavement was measured in the drill hole. The hole was then refilled with Lumnite cement concrete, which was protected from traffic for 24 hours. A sample of the subgrade soil was also taken from the shoulder four feet from the edge of the pavement and sometimes one from under the edge of the pavement at an angle of 45° with the surface. Both the subgrade soil samples and the concrete cores were labeled and shipped to the laboratory, the soil samples being transported in air-tight cans.

SCHEDULE FOR CLASSIFICATION OF PORTLAND CEMENT CONCRETE PAVEMENTS

CLASS A.—Perfect pavements showing no checks, cracks, pits or other signs of wear or deterioration.

CLASS B.—Pavements showing any or all of the following defects:

1. Hair-checks.
2. Minor pitting or scaling.

3. Negligible wear of the surface, expansion joints or edges.
4. Cracks not exceeding ½ the length or the width, and not creating a segment of the slab.

CLASS C.—Pavement similar to class "B" but in addition, showing any or all of the following defects:

1. Moderate deterioration or wear of surface, expansion joints or edges of the slab.
2. Narrow, unfaulted cracks not forming a segment less than approximately 100 square feet in area, but which may extend the full length or width of the slab.

CLASS D.—Pavements similar to class "C" but in addition showing any or all of the following defects:

1. Considerable deterioration or wear of surface, expansion joints or edges of the slab.
2. Moderate faulting or settlement at cracks or expansion joints.
3. Widening of cracks.
4. Cracks which divide the slab into several segments whose average area is between 50 and 100 square feet; or corner cracks which create a segment whose area is less than 50 square feet.

CLASS E.—Pavements showing any or all of the following defects:

1. Excessive deterioration or wear of minor portions of surface, expansion joints or edges of the slab.
2. Excessive faulting or settlement at expansion joints or cracks.
3. Plainly visible cracks which are so numerous that the slab is broken into segments having an average area of less than 50 square feet, but in which no more than minor disintegration occurs.
4. Repairs to the original pavement less than 10 square feet in area.

CLASS F.—Pavements so badly warped, broken, worn or disintegrated that a major portion of the slab requires replacement.

1. Repairs to the original pavement over 10 square feet in area.

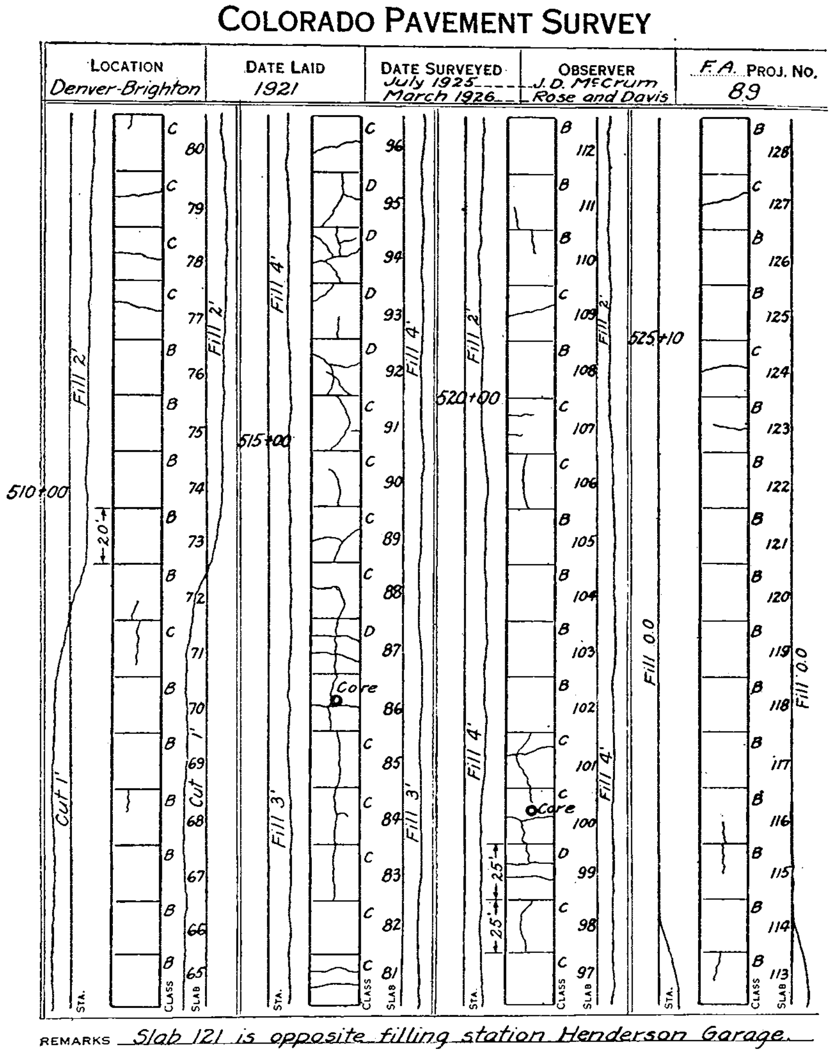


Figure 3.—A typical sheet of the pavement survey, data as transcribed from the field notes. A complete set of these sheets for all pavements studied is on file with The Colorado State Highway Department.

METHODS OF TESTING

The soil samples were tested for moisture content, moisture equivalent, lineal shrinkage, vertical capillarity, and grading, including determination of silt and clay percentages. These tests were recommended in 1925 by the Chief of Tests of U. S. Bureau of Public

Roads as those most likely to show the characteristics of the soils under investigation. The field method for determination of moisture equivalent percentage as proposed by Mr. A. C. Rose, U. S. Bureau of Public Roads, was used at first but later discarded and the centrifuge method used. All moisture equivalent test results given herein were obtained by the latter method.

SUBGRADE SOIL SAMPLES

1. Moisture Equivalent. See Appendix B.
2. Vertical Capillarity. See Appendix C.
3. Lineal Shrinkage. See Appendix D.
4. Mechanical Analysis. See Appendix E. In general the method used has been that described in "Public Roads," April, 1925. A few variations have been worked out which are believed to be more efficient and economical than the method referred to. The method described in "Public Roads" provides for decanting the supernatant liquid to a depth of 8 cm. after 8 minutes' sedimentation. In the method used in this investigation, the liquid was removed by means of a small glass siphon, which is illustrated in Fig. 4. The entrance

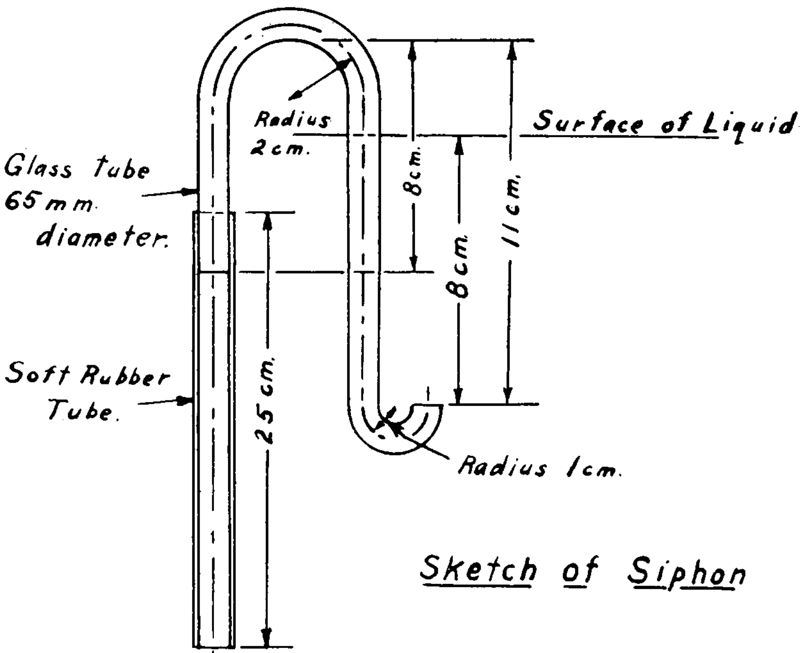


Figure 4.—A sketch of the glass siphon used in the mechanical analysis test.

Figure 5.—The layout used for mechanical analysis test when wash water was saved. Ten samples were treated at the same time.

end of this siphon was turned up so as to cause the water to move downward to the siphon, thus leaving the liquid below the 8 cm. depth undisturbed. By this method the entire 8 cm. depth was removed without danger of taking off particles other than clay. The danger of breaking the beaker was also reduced to a minimum. The siphon was removed from the beaker during filling and stirring, and hung on a convenient hook until the 8 minute sedimentation period had

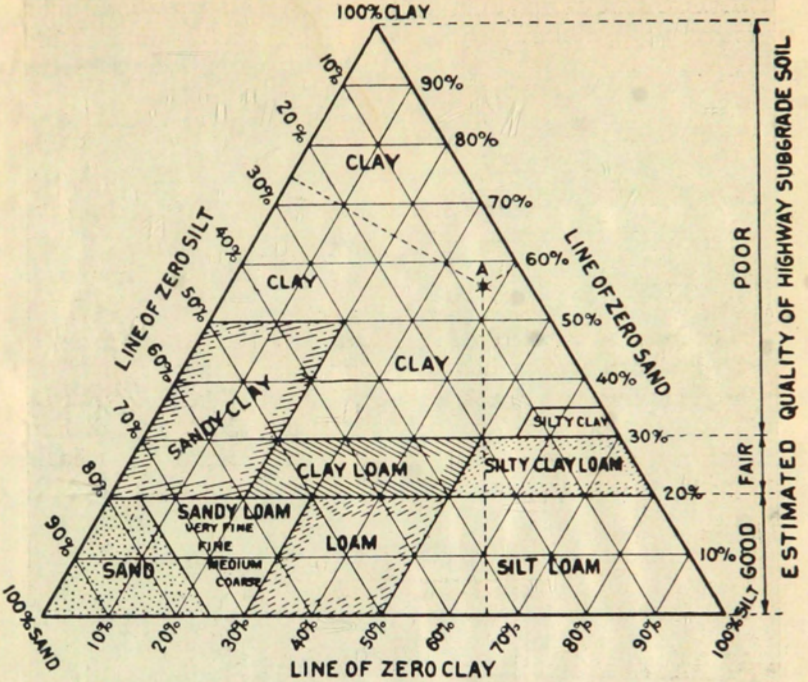


Figure 6.—Feret's triangle as adapted to soil classification.

Figure 7.—Concrete cores as received from field. Note variable length and uneven condition of ends which came from under side of pavement.

Figure 8.—Air hammer used for dressing ends of cores, also apparatus for holding cores.

elapsed. Ten samples of soil were in process of siphoning at the same time which was an item in reducing the cost of the operation.

With the method just described, it was not found necessary to save the wash water in order to check the results. This also greatly reduced the labor incident to this test.

The soils were classified, using Professor Feret's triangle as adapted to soil classification described by Mr. A. C. Rose in "Public Roads," August, 1924.

CONCRETE CORES—The concrete cores were dressed on both ends, capped, calipered and their specific gravity, absorption and ultimate compressive strength determined. For capping cores, a 1:1 mix of fine sand and Lumnite cement was used. This cap was applied after the cores had been stored in water for 48 hours. All cores were tested wet. As the length of the cores was variable, it was necessary to reduce the data to that which would have resulted had standard speci-

Figure 9.—The same cores as shown in Figure 7 after ends had been dressed.

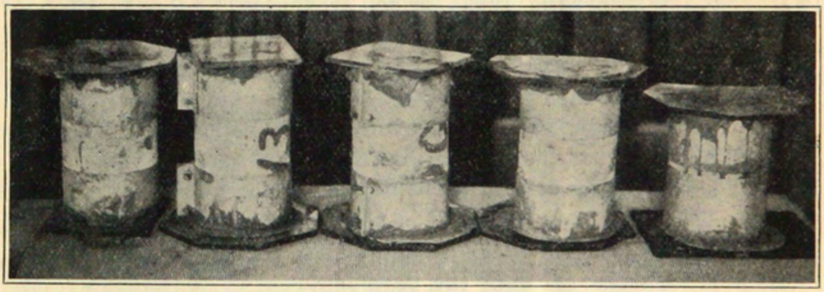


Figure 10.—Cores being capped with a 1:1 mix of Lumnite Cement and fine sand. The bands were made out of galvanized iron and fastened on with stove bolts. Glass plates were used on both ends.

Figure 11.—Cores after capping. Note smooth ends.

mens (length twice the diameter) been used. This was done by use of the factors specified in C42-25T, of the American Society for Testing Materials, entitled "Method of Securing Specimens of Hardened Concrete from the Structure."

QUESTIONNAIRE

Studies of data collected have been with the following questions in mind. While these have not all been answered conclusively in this report, it is hoped that some progress has been made along this line.

1. What relation exists between the compressive strength of the concrete and:
   a. The amount of wear on payment?
   b. The number of cracks which have been formed?
   c. The type of aggregate used?

2. What is the relation between the character of the subgrade soil and:
   a. The number of cracks formed in the pavement?
   b. Whether the cracks formed are longitudinal or transverse?
   c. Faulting at cracks or joints and settlement of slabs?
   d. Corner breaks?

3. What has been the effect of the drainage provisions used on:
   a. The number of cracks formed?
   b. Whether these cracks were longitudinal or transverse?
   c. Faulting or settlement of cracks and joints?

4. What has been the effect of the amount and character of the traffic on:
   a. Surface wear of the pavement?
   b. The formation of cracks?
   c. Wear at joints?

5. What has been the effect of maintenance on:
   a. The adequacy of drainage?
   b. The wear at joints?

6. What methods of treatment should be used where soils are considered to be unsatisfactory for subgrade purposes?

7. Assuming that the lineal shrinkage and moisture equivalent factors are suitable for showing the physical characteristics of subgrade soils, what are the safe limits of these factors for a saturated condition of the soil?

8. Should a saturated condition of the soil be assumed in all cases when planning subgrade treatment? If not what are the safe limits of the factors mentioned in Question 7 under these conditions?

9. Is it feasible to construct and maintain a drainage system which will obviate the necessity of subgrade treatment of poor soils?

PROJECT DISCUSSIONS

The project discussions which follow should be studied in conjunction with the data found in Tables 1 to 8 inclusive, the "Schedule for Classification of Portland Cement Concrete Pavements," on page 6, and the drawing and map furnished by the Colorado State Highway Department, which will be found in the inserted folder. On account of their great volume, it has not been thought feasible to include all of the data gathered from subgrade soil and concrete core tests in this publication. The data for each project has all been plotted on graphs similar to that in the insert at the back. A complete set of these graphs may be obtained from the Colorado Highway Department upon payment of the cost of printing.

The following discussions have been developed from the graphs and according to the following outline:

General Data.

Classification of Pavement.

Condition of Pavement as Affected by:
- Design.
- Strength of Concrete.
- Drainage.
- Subgrade Soil.
- Materials and Construction Details.
- Traffic.
- Maintenance.

Only those factors of the outline which are pertinent to the particular project have been included in the discussion.

STATE PROJECT (HEWITT'S)

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the C. B. & Q. R. R. underpass and extends northeasterly toward Brighton, a distance of 1.70 miles. The project was completed in October, 1918.

Classification of Pavement

This pavement falls largely in class "D" (See Classification Schedule page 7), due to surface wear and initial stages of deterioration at cracks, expansion joints and broken corners. Between Stations 26 and 43, a number of slabs fall in class "E" due to excessive wear at expansion joints and corners. Slabs shown as class "F" have been replaced or repaired by the Maintenance Department. The 1925 survey shows 81 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—A great many corner cracks occur, possibly as a result of the 6 in. edge thickness. The number of corner breaks is about 50 percent greater on the side of the pavement used by inbound traffic toward Denver than on the side used by outbound traffic.

STRENGTH OF CONCRETE.—The strength of concrete as indicated by 8 cores is rather erratic. The average strength is somewhat low, being only 3,830 lbs. per square inch.

DRAINAGE.—There are no indications that ground water approaches near enough to the surface to affect subgrade conditions. The country traversed by the highway is in general rather flat. The low grade line combined with shallow side ditches provides only fair surface drainage. The coarse texture of the soil overcomes to some extent the poor surface drainage conditions.

SUBGRADE SOIL.—Except for a short section of clay near the beginning of the project, the subgrade soil consists entirely of sand or sandy loam.

MAINTENANCE.—Between Stations 26 and 43, especially, considerable ravel and disintegration of expansion joints and slab corners was apparent at the time this classification was made. Improper, inadequate or poorly applied filler in the expansion joints and cracks, is doubtless the cause of this deterioration.

COLORADO F. A. P. 10

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the end of the State Project known as "Hewitt's Job" and extends northeasterly toward Brighton, a distance of 1.79 miles. The project was completed in 1920.

CLASSIFICATION OF PAVEMENT

The pavement of this project falls largely in class "C" due to surface wear, the gravel being quite noticeably exposed on the surface. Several stretches were placed in class "D" on account of ravel at expansion joints and broken corners. Considerable cracking has occurred but there is no pronounced series of either longitudinal or transverse cracks. The 1925 survey shows 60 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—Thin edges, coupled with heavy traffic have doubtless contributed to the formation of corner breaks.

STRENGTH OF CONCRETE.—The strength of the concrete, as indicated by tests of seven cores is fairly uniform.

DRAINAGE.—The country traversed by this project is quite flat both transversely and parallel to the roadway. No indications are apparent that ground water approaches near enough to the surface to affect subgrade conditions. The grade line is largely in fill and ample provision has been made for cross drainage. The side drainage is frequently interfered with by shallow ditches and barricades at farm entrances and small commercial establishments.

SUBGRADE SOIL.—The subgrade soil in general is very good, there being only one point at which the clay content rises above 20 percent.

MAINTENANCE.—A review of the records reveals no lack of maintenance on this project at any time. There is considerable ravel at the expansion joints at the present time. This ravel is caused by heavy traffic but may be due to lack of proper or adequate filler at times. Many of the expansion joints and cracks were badly in need of refilling with bitumen at the time of this inspection and classification of the pavement.

COLORADO F. A. P. 32

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the end of F. A. P. 10 and extends toward Brighton a distance of 5.74 miles. It was completed in 1921.

CLASSIFICATION OF PAVEMENT

The class "C" pavement is primarily due to wear, however, a great many cracks extending the full length or width of the slabs occur, which also place them in class "C." The "D" classification is largely due to corner breaks in addition to cracks and wear. At Stations 242 and 252 settlement and excessive wear are the cause of class "E" slabs. Between Stations 448 and 462 the road crosses seeped land on a 3-ft. to 5-ft. fill, composed of sandy material. Numerous longitudinal and transverse cracks, showing more or less spreading, faulting and settlement, occur in the pavement on this fill and place it in class "D." Cracks of a similar nature extend on to approximately Station 475 and place many slabs in this section in class "D." The 1925 survey shows 50 percent of the slabs on the project to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—The thin edges and heavy traffic, doubtless contribute to the formation of such corner breaks as exist on this project.

STRENGTH OF CONCRETE.—The strength of concrete as indicated by tests on 26 cores is fairly uniform.

DRAINAGE.—The drainage conditions from the beginning of the project to Station 448 are good, except for a few stations where side ditches are shallow or obstructed by small commercial establishments. From Stations 448 to 462, the road crosses low, wet land. This wet condition is caused by seepage from an irrigation canal above the road. From Stations 462 to 475 seepage is also apparent, probably originating from the same source.

SUBGRADE SOIL.—The subgrade soil in general is good, being composed of sand, sandy loam or clay loam. A stretch of clay soil occurs between Stations 300 and 320; however, since the drainage is good, only a few cracks occur in this section. Between Stations 448 and 462, the badly cracked pavement is doubtless due to unequal settlement of the sandy fill caused by the unstable condition of the underlying soil, rather than to poor material in fill itself.

COLORADO F. A. P. 89

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the end of F. A. P. 32 and extends northeasterly 4.4 miles toward the town of Brighton. It was completed in 1921.

CLASSIFICATION OF PAVEMENT

The pavement on this project falls largely in class "B" so far as wear or deterioration of the surface is concerned. A large number of both longitudinal and transverse cracks occur, however, which place a large percentage of the slabs in class "C" and a few in class "D." The number of cracks decreases toward the north end of the project. This is probably due to better drainage conditions. The 1925 survey shows 49 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DRAINAGE.—This project follows down the South Platte River Valley. The country traversed is quite level both transversely and parallel to the highway. There are no indications that ground water approaches near enough to the surface to affect subgrade conditions. Transverse drainage is well taken care of by small structures. No streams of any consequence are crossed on the project. The road grade in general is in light fill and the side drainage is good, except for a few short stretches where the ditches are shallow or obstructed by farm crossings or small road-side commercial establishments. A low grade line in places, coupled with a clay soil, is a possible cause for some of the transverse cracking. Where longitudinal cracks occur they are as a general rule found on fills.

SUBGRADE SOIL.—The larger part of the cracking which exists on this project occurs where the subgrade is clay or clay loam. However, from Stations 660 to 700, the subgrade soil is clay and there are fewer cracks than at other places on the project.

COLORADO F. A. P. 148

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the end of F. A. P. 89 and continues northeasterly 1.17 miles to the town limits of Brighton. Beginning again at the north town limits of Brighton, it continues northeasterly 3.60 miles toward Fort Lupton. The project has a total length of 4.77 miles. It was completed in 1922.

CLASSIFICATION OF PAVEMENT

The condition of the pavement in general appears to be good, placing it in class "B." Wear of the surface caused by heavy steel tired beet traffic for a distance of about one-half mile south and one mile north of the town of Brighton, places these two sections in class "C." Most of this wear is confined to the inbound traffic side of the pavement. A similar condition occurs to a lesser extent near the north end of the pavement in the vicinity of a beet dump located opposite Station 160. The 1925 survey shows 37 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE.—The strength of concrete as indicated by 22 cores varies quite widely. The average strength is approximately 4,540 lbs. per sq. in., which is fair, but the lowest strength is 3,080 lbs. per sq. in., and the highest, 5,740 lbs. per sq. in. The low strength occurs at Station 116.

DRAINAGE.—The project follows down the east side of the Platte River Valley. The country traversed is quite flat both transversely and parallel to the highway. There are no indications that ground water approaches near enough to the surface to affect subgrade conditions. Transverse drainage is well taken care of by small structures. No streams of any consequence are crossed on the project. The road grade in general is in light fill which together with moderately deep ditches renders side drainage good.

SUBGRADE SOIL.—The subgrade soil is mostly sandy loam or clay loam. Two stretches of clay soil are found from Stations 765 to 785 and from 135 to 155. As drainage conditions are generally good the clay in these sections does not appear to have caused any increase in the amount of cracking.

TRAFFIC.—The 1925 traffic census report of the Colorado Highway Department shows estimated traffic totals of 2,407 and 3,208 vehicles per day south and north of Brighton, respectively. Of these totals truck traffic constitutes approximately 20 percent. The increased traffic north of Brighton is probably due to local beet hauling in the vicinity of the factory of the Great Western Sugar Company, which is located at the north edge of town.

COLORADO F. A. P. 226-A

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the end of F. A. P. 148, and extends northeasterly 8.22 miles through the town of Fort Lupton and on toward Platteville. It was completed in 1923.

CLASSIFICATION OF PAVEMENT

From Stations 190 to 250 the pavement classification alternates between classes "B," "C" and "D." The class "C" is due largely to wear and class "D" to corner breaks in addition to wear. From Stations 250 to 343, at the north side of Fort Lupton, the pavement falls in class "C" due primarily to wear caused by heavy steel-tired beet traffic. But very few cracks exist in this section of the pavement. From Stations 343 to 448 in the vicinity of the factory of the Great Western Sugar Company, excessive wear due to concentrated heavy steel-tired beet traffic places the pavement in class "D." Only a nominal number of cracks occur in this section and these are largely longitudinal. At Station 448 a decided reduction in beet traffic due to a cross-road has caused a marked decrease in wear. Moderate wear extends to about Station 480, placing the pavement essentially in class "C." Form Stations 510 to 540 another stretch of class "C" pavement occurs on account of moderate wear due to heavy steel-tired beet traffic in the vicinity of a beet dump. Two prominent series of longitudinal cracks also occur in this section. The balance of the pavement on this project falls essentially in class "B" with occasional class "C" slabs due to cracks. The 1925 survey shows 27 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—At six points, the measurements show only a 7-inch thickness, and at one point a 6½-inch thickness was recorded. No particular weakness or increase in the number of cracks is apparent where the thinner portions occur. A series of corner breaks near the beginning of the project indicates a weakness, possibly due to thin edges.

STRENGTH OF CONCRETE.—The strength of the concrete as indicated by tests on 28 cores is fairly uniform except for a stretch of approximately two miles in the vicinity of Fort Lupton where it appears to be somewhat below normal. Data are lacking within the town limits of Fort Lupton.

DRAINAGE.—There are no indications that ground water approaches close enough to the surface at any point to affect subgrade conditions.

In general the grade was constructed well above the ground line. No large streams are crossed on the project. Local drainage in general is well taken care of by minor cross drainage structures. Ample side ditches from 2 ft. to 3 ft. deep exist on both sides of the road and provide good surface drainage.

SUBGRADE SOIL.—The subgrade soil on this project is essentially sandy loam or clay loam. One short stretch of sand, one of clay, and two of sandy clay exist.

Near the beginning of the project considerable longitudinal cracking occurs where a clay loam soil exists. However, low strength concrete also is found at this point. In general there appears to be more cracking where the subsoil is sandy clay or clay loam than on the sandier types. Such cracks as occur are mostly along the center line of the pavement.

A peculiar type of clay soil was found near Station 565. This showed a moisture equivalent of 33 percent by the centrifuge method and 19.3 by the field method. This soil absorbed water very slowly and appeared to mat in the bottom of the container and prevented the water being thrown off by centrifugal force. The top of the sample retained a wet, shiny appearance after being subjected to the moisture equivalent test. No ill effect is noticed in the pavement in the vicinity where this sample was taken.

COLORADO F. A. P. 226-B, 35 AND 226-D

U. S. HIGHWAY 85 DENVER-GREELEY

As these three projects are all short and contiguous they will be treated together, although they were built at different times. F. A. P. 226-B begins at the end of F. A. P. 226-A and the three projects here considered extend northeasterly a distance of 5.22 miles through the town of Platteville.

F. A. P.	35	was completed in	1920.
"	226-B	"	1924.
"	226-D	"	1925.

CLASSIFICATION OF PAVEMENT

F. A. P. 226-B. The pavement on this project is essentially class "B" throughout. Between Stations 625 and 659, the pavement is in exceptionally good condition, only minor defects such as pits, hair-checks, etc., occurring. Between Stations 659 and 723, south of Platteville, and between Stations 844 and 897, north of Platteville, a moderate amount of cracking occurs which places occasional slabs in class "C." Corner breaks cause a few class "D" slabs. The 1925 survey shows 27 percent of the slabs to have been cracked.

F. A. P. 35. The pavement on this project varies between classes "B," "C" and "D," due to varying degrees of ravel at expansion joints and moderate surface wear. Considering the age of this pavement, the slabs are noticeably free from serious cracks. The 1925 survey shows 30 percent of the slabs to have been cracked.

F. A. P. 226-D. The pavement on this project is almost perfect, the surface being almost free from any kind of imperfections. Only two slabs on the project show cracks.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—That portion of 226-B north of Platteville showed a thickness of less than that specified at all points of observation.

STRENGTH OF CONCRETE.—The average strength of the concrete on these three projects is high, that on F. A. P. 35 being the highest shown on any project thus far discussed. The ravel and wear on F. A. P. 35 is thus manifestly not due to lack of strength in the concrete.

DRAINAGE.—The drainage conditions on F. A. P. 226-B are good throughout. The grade line is high and ample side ditches have been provided. No streams of any consequence except one large irrigation canal are crossed on the project.

On F. A. P. 35 the grade line is somewhat lower than on F. A. P. 226-B and side ditches are shallower. Cross drainage is amply provided for and as a whole no ill effects are apparent in the pavement due to lack of drainage.

On F. A. P. 226-D the grade line is low, especially on the section through the town of Platteville. Side ditches are also necessarily shallow on this section on account of being in town. Ample provision has been made for cross drainage.

On none of these three projects does the lack of drainage provisions appear to have affected the quality or condition of the pavement.

SUBGRADE SOIL.—The subgrade soil on these three projects is essentially sandy loam or clay loam. About one-half mile of clay soil is found on F. A. P. 35 and a short section of sandy clay at the junction of F. A. P. 226-B and 35. Since there are but very few cracks on F. A. P. 35, the increase in clay content of the soil does not appear to have affected the condition of the pavement. Such cracks as exist on these three projects do not appear to be associated with any particular type of soil.

MAINTENANCE.—On F. A. P. 35 the ravel at expansion joints is evidently due to lack of filler and proper maintenance.

COLORADO F. A. P. 226-C

U. S. HIGHWAY 85 DENVER-GREELEY

This project begins at the end of F. A. P. 226-B and extends northeasterly 10.73 miles toward Greeley. It was completed in 1924.

CLASSIFICATION OF PAVEMENT

The pavement is essentially class "B," being in good condition throughout. A few transverse cracks cause occasional class "C" slabs. The 1925 survey shows 12 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—This project was constructed in two sections by different contractors. Transverse expansion joints are 60 ft. apart. A longitudinal center line joint was provided between Stations 117 and 474. Apparently no more longitudinal cracks have occurred when no center line joint was provided than where it was used. This is doubtless due to the coarse texture of the subgrade soil and to good drainage.

STRENGTH OF CONCRETE.—Slightly higher average strength is shown on Paving Division No. 1 than on No. 2. Division No. 1, however, is more erratic in strength than No. 2. No difference in the condition of the pavement is apparent where the core strength is relatively low.

DRAINAGE.—This project traverses a rolling, sandy, upland section of country where drainage conditions as a rule are exceptionally good. No streams of any consequence except one large irrigation canal are crossed. The grade line is high, deep side ditches have been constructed and local surface drainage is amply provided for by means of cross drainage culverts. The good drainage conditions are reflected in the condition of the pavement. Between Stations 530 and 540 where the road is on a rather high fill across a wet sag, some cracking is evidently due to unequal settlement of the fill.

SUBGRADE SOIL.—The subgrade soil is essentially sand or sandy loam. Two short stretches of clay loam and one of sandy clay exist. The condition of the pavement does not appear to be adversely affected on the portions where soils with higher clay content are found.

COLORADO F. A. P. 131

U. S. HIGHWAY 85 DENVER-EAST

This project extends eastward from the Denver city limits 0.83 miles toward Aurora. It was built in 1922.

CLASSIFICATION OF PAVEMENT

The pavement is largely class "B," with a few transverse cracks resulting in occasional class "C" slabs. The 1925 survey shows 14 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DRAINAGE.—There are no indications that ground water is high enough to affect subgrade conditions. As a rule, side ditches are shallow and the grade line close to the original surface.

COLORADO F. A. P. 31

U. S. HIGHWAY 85 DENVER-EAST

This project extends eastward from the end of F. A. P. 131 to the Fitzsimons Hospital, a distance of 1.17 miles. It was built in 1920.

CLASSIFICATION OF PAVEMENT

The pavement classifications vary between class "B" and class "C." The "C" classification is due largely to transverse cracks. One series of longitudinal cracks occur on a light fill between Stations 61 and 65. A few slabs fall in class "D" due to corner breaks. The 1925 survey shows 59 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—The thin edges together with heavy traffic may be the cause of some of the corner breaks.

STRENGTH OF CONCRETE.—The strength of concrete as indicated by drill cores is rather erratic, and there is only one other project showing as low strength.

DRAINAGE.—The drainage conditions on the first 2,000 ft. are classified as only fair, due to a low grade line, a low gradient and shallow ditches. The balance of the project is rated as good on account of better side ditches, slightly higher fills and a higher gradient. There are no indications that the ground water is high enough to affect the subgrade conditions at any place on the project.

STATE PROJECT (GOLDEN ROAD)

U. S. HIGHWAY 40 DENVER-GOLDEN

This project begins at the west city limits of Denver at the intersection of Colfax avenue and Sheridan boulevard, and extends westerly 8.8 miles to the town of Golden.

CLASSIFICATION OF PAVEMENT

Note: The stationing on the study graph refers to pavement slabs. These are normally 30 ft. long and are plotted 20 to the inch.

Surface wear is the controlling factor in the classification of the pavement for the first 200 slabs. Replacement of minor portions of several slabs on account of ravel and broken corners increases the normal "D" to an "E" classification. On the remainder of the pavement more or less wear on the surface and ravel at the expansion joints continues nearly to Golden, but the principal factor upon which the classification depends is the prevalence of cracks. Transverse cracks are especially characteristic of this project. This is doubtless due to a uniformly low grade line combined with a clay subgrade soil which at certain times of the year is known to be saturated with moisture. Several peaks occur in the classification where poor drainage conditions in addition to poor subgrade soil exist. The 1925 survey shows 81 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—There are no more cracks on the first mile where the sand cushion was omitted than on the rest of the project where it was used. Quite a number of corner breaks exist at the present time and numerous breaks have been repaired by the maintenance department. These cracks are doubtless due to the pavement being too thin at the edges.

STRENGTH OF CONCRETE.—The strength of the concrete as shown by tests on 39 cores is very erratic. The high average and maximum strengths are doubtless due to the excellent quality of the crushed trap rock from a quarry near Golden, which was used as coarse aggregate.

No explanation is forthcoming from the study data as to why the core strengths should vary so widely in the extremes or so much from point to point. There appears to be no particular relation between the strength of individual cores and the condition of the pavement at corresponding points.

DRAINAGE.—The east half, or Denver end of the project, traverses a flat country rising gradually to the westward. The west end of the project traverses the foothills where a more rolling grade line prevails.

The grade line as a rule is low and the side ditches are shallow throughout the length of the project. Cross drainage is amply taken care of, but the side ditches are frequently obstructed and, in many places, almost completely filled. This is especially true near the Denver end of the project.

No borings were made to determine the elevation of the water table but there are indications that ground water approaches the surface in several places. In the neighborhood of slabs 450 to 460 and 560 to 570, the road crosses swampy draws. At these points bad settlement and cracking of the slabs has occurred.

SUBGRADE SOIL.—Heavy clay soil coupled with poor drainage conditions is doubtless the principal cause of the large number of transverse cracks existing. Poor drainage permits high soil moisture content with consequent reduced soil bearing power and heaving due to frost action. Information gathered from local citizens is to the effect that at times during the year, ground water has been observed to ooze from expansion joints and cracks and to stand on top of the pavement.

TRAFFIC.—Obviously, traffic has been heaviest near the Denver end of the project. This is also manifest by the wear on the pavement surface, which is quite extensive near Denver but decreases as you proceed outward from the city. One important diversion of traffic occurs at the Rifle Range where the Vernon Canon road diverges.

MAINTENANCE.—At the time the classification of the pavement was made, lack of maintenance was in evidence, especially on the Denver end of the project where the side ditches were partly filled and the culverts were clogged with dirt and trash. Raveled and broken slabs have been kept quite well repaired, but considerable new repair work was needed in 1926.

Lack of maintenance in keeping the drainage system open and operative is a possible source of some of the cracks in the pavement, as it permits the subgrade to become over-saturated with moisture.

COLORADO F. A. P. 129

U. S. HIGHWAY 285 DENVER CITY LIMITS, NORTH

This project begins at the north city limits of Denver at the end of Federal boulevard and extends north 4.424 miles. Construction was started in September, 1921, and completed in August, 1923.

CLASSIFICATION OF PAVEMENT

The pavement on this project falls essentially in class "C" throughout. There are occasional class "D" slabs or small groups of class "D" slabs due to open cracks, some faulting and corner breaks. The thickness of the pavement as shown in Table 1 does not appear to be reflected in the classification.

Near the beginning of the project, from Stations 130 to 140 and from Stations 170 to 190, the classification is somewhat improved due, doubtless, to better drainage conditions provided by a rolling grade line. The pavement survey made in April, 1926, shows 43 percent of the pavement slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE.—The strength of the concrete is much more uniform toward the north end of the project. The average compressive strength of the concrete on this project is about the average for the Denver-Fort Collins pavement and approximately 700 lbs., or 15 percent higher than that on the Denver-Greeley road. The badly cracked condition of parts of this project is evidently not due to low strength concrete.

DRAINAGE CONDITIONS.—From Station 35 to Station 75, crossing Clear Creek bottom, the natural drainage conditions are poor. The water table approaches close to the ground surface and the side ditches and borrow pits contain more or less water most of the time, as no outlets were constructed. The pavement was laid on an old fill approximately four feet high. This fill was well compacted, had been surfaced with gravel and rests on a gravel subsoil. The soil composing this fill is classed as clay or sandy clay and showed at the time of the pavement survey approximately 15 percent of moisture. On this section of the project very little settlement or cracking of the pavement has occurred. This is probably due to the fact that the fill had been well compacted and established prior to the time the pavement was laid and that it rests upon a stable foundation. It is evident that such movements of the pavement as have occurred due to changes in temperature or in the moisture content of the fill, have been uniform and relatively harmless.

On the balance of the project, that is, from Stations 0 to 35 and from 75 to 234, the natural drainage conditions are good, due to a rolling grade line and the absence of excessive ground water. The artificial drainage conditions, however, are not of the best. The grade line is close to the original ground surface and only shallow side ditches were constructed.

SUBGRADE SOIL.—The subgrade soil on this project is essentially clay.

The old road bed upon which the pavement was laid had been surfaced with gravel. In many places this surfacing was not removed when the concrete pavement was laid. A study of the crack record and soil data in connection with the old and the new profiles reveals the following facts in addition to what was stated in the above paragraph on drainage:

Between Stations 85 and 87, and 95 and 100, the old road surfacing was removed and the pavement laid on the natural clay soil. At these points considerable cracking accompanied by spreading and settlement has occurred.

From Stations 103 to 107, the original fill, which was from 8 to 10 feet high, was raised an additional 6 feet and widened at the time the pavement was laid. The pavement on this fill shows considerable settlement and cracking.

From Stations 116 to 140, the profile shows the pavement to have been laid on a very light fill or immediately upon the old graveled road bed. This section is noticeably free from cracks.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel used on this project came from Clear Creek. The sand contained a high percentage of fines. According to a statement by Major Donovan, the Division Engineer, the aggregates used from the beginning of the project to about Station 200 were hauled directly from the pit and used in a moist condition, while those used on the balance of the project were stockpiled and became thoroughly dry before being used. A survey of the pavement made in 1923 shortly after it was laid shows that a large number of hair-checks existed near the north end of the project. It is possible that the dry condition of the aggregates, in addition to the dry and hot weather which prevailed at the time of the laying of the pavement contributed to this hair-checking.

According to the 1923 survey, 15 percent of the slabs were hair-checked. The 1926 pavement survey shows that 65 percent of the hair-checked slabs have developed major cracks, while only 38 percent of the non-hair-checked slabs have done so. From these observations, it is evident that hair-checks have created a weakness in the pavement which has caused an increase of 71 percent of major cracks in the slabs affected.

TRAFFIC.—Considerable heavy truck traffic originates in the Clear Creek bottom from gravel plants located near the road.

COLORADO F. A. P. 133

U. S. HIGHWAY 285 DENVER-BROOMFIELD

This project begins at the north end of F. A. P. 129 and extends north a distance of 4.223 miles. Construction was started in November, 1921, and completed in August, 1923.

CLASSIFICATION OF PAVEMENT

The pavement on this project falls essentially in class "C." A considerable number of slabs, or small groups of slabs, however, have been given the "D" or "E" classification on account of bad cracks, warping and settlement. Surface wear of the pavement is not much in evidence but there are numerous hair-checks and pits. The pavement survey made in April, 1926, shows 71 percent of the slabs to have been cracked. A comparison of the pavement surveys made in 1923 and 1926 shows a remarkable conformity of hair-checked slabs in the former, with badly cracked slabs in the latter.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—Section B, which was used on this project is believed to be faulty, in that no provision has been made for lateral drainage of moisture entrapped in the sand cushion. Moisture reaching the sand cushion through expansion joints, cracks and gravel shoulders, has little chance to escape except downward through the subgrade soil. Although the natural drainage conditions on the project are good, the moisture content of the subgrade samples secured from the core drill holes is high. This has possibly contributed to the cracking and settlement, which have been considerable.

STRENGTH OF CONCRETE.—The strength of the concrete on this project is about equal to the average found on the Denver-Fort Collins road. The badly cracked condition of parts of this pavement is evidently not due to low strength concrete.

DRAINAGE.—This project traverses a rolling upland country where the natural drainage conditions are exceptionally good. No streams of importance are crossed. Adequate provision is made for all cross drainage. The grade line, however, is low and as a rule the side ditches are shallow. The low grade line and shallow side ditches coupled with a heavy clay subgrade soil and no provision for lateral drainage of water entrapped in the sand cushion is believed to be contributary to the badly cracked condition of the pavement.

SUBGRADE SOIL.—The subgrade soil on the project is comparatively uniform and is essentially clay with one short stretch of clay loam and one of sandy clay.

MATERIALS AND CONSTRUCTION DETAILS.—Statements made by Major Donovan, Division Engineer, set forth the following facts:

a. The prevailing weather conditions during the construction season were very dry, hot and often windy.

b. As a rule the old gravel road surface was not scarified before reshaping the subgrade for the pavement. The grade was prepared some time in advance of paving operations and became very dry and dusty. A roller weighing 200 lbs. per lineal inch was used to compact the subgrade but with very little effect on account of its dry, dusty condition.

c. The sand and gravel came from Clear Creek. They were stockpiled for several months and became dry before being used.

d. The sand cushion material was stockpiled on the subgrade and spread and thoroughly sprinkled just before concrete was placed.

e. The concrete was mixed relatively dry and a mechanical tamper and finisher was used.

f. A large percentage of the slabs showed serious hair-checking soon after the pavement was finished.

g. The traffic over the road includes some heavy units and the pavement developed many longitudinal cracks soon after it was opened to traffic.

An examination of the 1926 pavement condition survey in connection with the profile and cross sections reveals that some of the most serious cracking has occurred where the grade line was altered, that is, in new cuts or on new fills. These cracks perhaps are best attributed to unequal settlement of the subgrade soil. In other places serious cracks have developed where the pavement was laid on a fill of only a few inches over the old graveled road crown. These cracks are doubtless due to settlement on an unequally compacted subgrade.

A pavement survey of the project made by the Division Engineer in the spring of 1923 shows that approximately 29 percent of the slabs were hair-checked. The 1926 pavement survey shows that 87 percent of the hair-checked slabs have since developed major cracks while only 63 percent of the non-hair-checked slabs have developed major cracks. From these observations it appears that hair-checks have created a weakness in the payment which has resulted in an increase of 38 percent of major cracks in the slabs affected.

COLORADO F. A. P. 222-A

U. S. HIGHWAY 285 DENVER-BROOMFIELD

This project begins at the north end of F. A. P. 133 and extends a distance of 2.737 miles westward to the town of Broomfield. Construction was started in June, 1922, and completed in April, 1923.

Classification of Pavement

The pavement on this project falls largely in class "C." Several slabs near Station 574 were given the "D" classification on account of excessive cracking, and a few individual slabs were placed in class "D" on account of corner breaks.

Hair-checks were even more prevalent on this project than on F. A. P. 133. Approximately 50 percent of the slabs developed more or less hair-checks. The 1926 pavement survey shows that 73 percent of the hair-checked slabs have since developed major cracks. Of the non-hair-checked slabs only 53 percent have developed major cracks. From these observations the deduction naturally follows that hair-checks have been responsible for an increase of 38 percent of major cracks in the slabs affected. The 1926 survey shows 63 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DRAINAGE.—The natural drainage conditions consist of a gently rising slope to the westward or in the longitudinal direction of the project. The transverse slope is also very slight and no streams of any importance are crossed. The adjacent land is all under irrigation and at times waste water encroaches on the right-of-way in several places. At Station 574, a small stock reservoir is located on the north side of the road. The subgrade soil sample taken from under the center line of the pavement at this point shows a moisture content of 24.2 percent, a moisture equivalent of 25.8 and a stability factor of 1.06. Seepage from the reservoir, and as a consequence, a softening of the subgrade, is possibly the cause of the badly cracked condition of the pavement at this point. At the time the soil samples were secured seepage water stood in the side ditch between the reservoir and the road. Local inhabitants have stated that water oozes from expansion joints and cracks in the pavement in this locality at certain seasons of the year. Other observations indicate that similar conditions prevail above the reservoir and extend almost to Broomfield. The grade line is low and the side ditches are shallow throughout most of the project.

The plans show that a tile drain was provided on the north side of the road from Station 488 to Station 546-40 and on the south side from Station 511-60 to 532-80. The tile drains were laid directly underneath the ditch line and at depth of 4 feet below the crown of the pavement. These drains were provided to take care of seepage water from irrigation which is bad on the sections mentioned. They have apparently been successful in that function as the condition of the pavement on these sections of the road is no worse than that on the rest of the project.

SUBGRADE SOIL.—The subgrade soil on this project is clay, which is quite uniform in character.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel came from Clear Creek, or from the same source as the materials used on F. A. P. 133. The pavement was laid the same season and under the same general climatic and physical conditions as described in the discussion of F. A. P. 133.

COLORADO F. A. P. 222-B

U. S. HIGHWAY 285 BROOMFIELD-LAFAYETTE

This project begins at the west end of F. A. P. 222-A and extends northwesterly 1.518 miles. Construction was begun October, 1922, and completed in September, 1923.

CLASSIFICATION OF PAVEMENT

The 1926 survey places the pavement, essentially, in two classes. From the beginning of the project to Station 633, the "B" classification prevails with an occasional "C" slab due to transverse cracks. At Station 633, the classification changes abruptly to "C" and continues thus to the end of the project with occasionally a "D" and an "E" slab due to corner breaks, settlement and spreading of cracks. The 1926 survey shows 17 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE.—The strength of concrete is somewhat above the average strength for the Denver-Fort Collins road.

DRAINAGE CONDITIONS.—The project traverses a rolling upland country where the natural drainage conditions, as a rule, are good. A low, wet draw at the head of a small artificial lake is crossed at Station 635. Tile drains were provided and the fill raised from five to six feet across the wet area. As a result there is no excess cracking on this fill.

At Station 645 where the contractor had his mixing plant located on a high cut bank and more or less water was spilled on the road, making the subgrade soft and plastic, two slabs have developed serious cracks, warping, and settlement.

COLORADO F. A. P. 222-C

U. S. HIGHWAY 285 BROOMFIELD-LAFAYETTE

This project begins at the north end of F. A. P. 222-B and extends north a distance of 2.825 miles. Construction was started in October, 1923, and completed in January, 1925.

CLASSIFICATION OF PAVEMENT

The 1926 pavement survey shows the condition of the pavement to vary from class "B" to class "F." From the beginning of the project at Station 682 to Station 770, the prevailing conditions place most of the slabs in class "C" but on account of poor subgrade conditions, causing heaving and warping of the pavement in cuts and settlement on fills, several groups of slabs have been placed in classes "D," "E" and "F" according to degree of failure.

From Station 771 to the end of the project the prevailing condition is class "B" with occasionally a slab or small groups of slabs falling in class "C" due to more extensive cracks. Sixteen percent of the slabs were cracked in 1926.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—Considering the failure of the pavement at several points, it is obvious that the design has not been adequate to cope with all conditions prevailing on this project. Inadequate drainage provisions are doubtless the principal defect in design.

STRENGTH OF CONCRETE.—There is no evidence of weakness in the concrete which would cause failure of the pavement on this project.

DRAINAGE.—The south end of the project from Stations 682 to 736 traverses rolling ground where the natural drainage conditions are good. Three short, deep draws are crossed on this section. The balance of the project lies on flat or slightly rolling ground where drainage conditions vary. Rock Creek is crossed by an 80-ft. span pile trustle at Station 756. At Stations 795 to 797-50, the road passes through a 4-ft. cut. At the highest point in the cut, an irrigation ditch crosses the road in an inverted siphon. During construction, spring water appeared in the bottom of the cut. In order to remedy this condition, the soil was excavated to a depth of two feet below grade at the siphon and tapered to a depth of six inches, 100 feet on each side of the siphon. The excavation thus made was refilled with gravel. Tile drains were also installed under the ditches on either side of the road to assist in draining the subgrade. As a result no serious cracks or settlement of the slabs have occurred at this point.

Between Stations 798 and 804 the road crosses a small swamp on a three-foot fill. An open ditch was constructed on either side of the road with a tile drain at right angles for an outlet. Some delay occurred at the time of construction in order to allow time for the fill to dry out before laying the pavement. No serious cracks or appreciable settlement of the slabs have occurred on this fill. This is evidently due to adequate drainage having been provided.

SUBGRADE SOIL.—The prevailing soil classification is clay, and the moisture equivalent, lineal shrinkage and vertical capillarity percentages are all high.

A peculiar soil condition occurred in the cut from Stations 719 to 725. The material had the appearance of a fine textured sand rock but was in reality a shale. It was necessary to shatter the shale with powder before it could be removed with a steam shovel. After being exposed to the elements, however, it disintegrated very rapidly. The fill, Stations 710 to 719, built of this material settled badly, and several slabs have had to be removed. The material in the cut when saturated with moisture heaved badly under frost action, and several slabs have had to be replaced here, also. The clay content in the soil samples from this cut ran as high as 54 percent with an additional 33 percent of silt. The pavement classification shows several high peaks which are due to poor subgrade conditions, or to methods of construction. One of the writers witnessed the removal of a badly warped and cracked slab on the fill at Station 711 in the summer of 1926. One corner of the slab had settled as much as nine inches. After removing this slab the subgrade under the slab next above was observed to have settled away leaving the slab cantilevered half the width of the pavement. The subgrade material under the pavement was thoroughly saturated and evidence existed of running water under the pavement. The source of the water is not definitely known but it is believed that it was surface water which found its way into the sand cushion through expansion joints, cracks and the gravel shoulders. The slabs removed were at the foot of a 6 percent grade approximately 1,200 feet long.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel used on this project came from pits on Boulder Creek about five miles north of the project. A roller weighing approximately 200 lbs. per lineal inch was used in compacting the fills. Some rolling was also done in the cuts, especially those near the south end of the project. The cut, Stations 719 to 725, was made during the winter season. The use of frosted lumps of material removed from the cut is a possible source of some of the settlement which took place in the adjacent fill.

COLORADO F. A. P. 281-A

U. S. HIGHWAY 285 BROOMFIELD-LAFAYETTE

This project begins at the north end of F. A. P. 222-C and extends toward Lafayette a distance of 1.249 miles. Construction was started in July, 1924, and completed in April, 1925.

CLASSIFICATION OF PAVEMENT

The 1926 pavement survey shows the pavement to be essentially class "B" with two short sections of class "C" and one of class "D" slabs, due to wear, settlement and cracking. Only 5 percent of the slabs on this project were cracked in 1926.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—The pavement design used provides for thickened edges, a longitudinal center line joint and transverse expansion joints 60 ft. apart. From the present condition of the pavement it appears that this design has satisfactorily met local conditions.

STRENGTH OF CONCRETE.—The strength of the concrete on this project is slightly above the average.

DRAINAGE.—This project traverses slightly rolling ground where the natural drainage conditions are good. There is no evidence that ground water approaches the surface at any point except possibly from Stations 873 to 876, where there are several cracked slabs.

SUBGRADE SOIL.—The subgrade soil on this project is essentially clay. There is one short stretch of sandy clay and one of clay loam.

COLORADO F. A. P. 281-B

U. S. HIGHWAY 285 LONGMONT-LAFAYETTE

This project begins at the south end of F. A. P. 88 and extends south a distance of 3.068 miles. Construction was started in July, 1924, and completed in July, 1925.

CLASSIFICATION OF PAVEMENT

The pavement on this project is essentially class "B." There are occasional class "C" slabs due to cracks. The cracking is not serious at any point and only 6 percent of the total number of slabs on this project were cracked in 1926.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE. — Only five cores were taken. This number is not sufficient for a proper study of all conditions that may exist on the project. The strength of the five cores taken is remarkably uniform and averages approximately 700 lbs. per sq. in., or 13 percent higher than the average of pavements tested on the Denver-Fort Collins road.

DRAINAGE.—This project traverses a slightly rolling upland country where the natural drainage conditions are good. No streams of any consequence are crossed. The condition of the pavement does not indicate that the drainage provisions have been insufficient.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel used came from Boulder Creek. A central proportioning plant was used and the pavement was hand tamped and finished. The fills were built the same season that the pavement was laid. The subgrade was moderately rolled with a horse-drawn roller.

COLORADO F. A. P. 14, 36 AND 88

U. S. HIGHWAY 285 LONGMONT-SOUTH

These three projects are old projects and were built under the same design. The pavement and subgrade data are plotted on the same graph, hence they will be considered together. F. A. P. 14 is 0.504 miles long. Construction was started in October, 1919, and completed in May, 1920. F. A. P. 36 is 1.182 miles long. Construction was started in February, 1921, and completed in October, 1922. F. A. P. 88 is 1.117 miles long. Construction was started in April and completed in December, 1921.

CLASSIFICATION OF PAVEMENT

The classification improves very materially as the road extends outward from the town of Longmont. The prevailing "D" and "C" classification depends largely on surface wear and ravel at expansion joints and cracks. The "E" slabs at Stations 15 and 27 are due to settlement at bridges. The "E" slabs at Station 24 are due to frozen concrete. The 1926 pavement survey shows 42 percent of cracked slabs on F. A. P. 14, 15 percent on F. A. P. 36, and 19 percent on F. A. P. 88.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE.—The average strength of the cores taken on F. A. P. 14 is 4 percent below the average, on F. A. P. 36, 20 percent above the average, and on F. A. P. 88, 14 percent below the average of all projects studied between Denver and Fort Collins. The high average strength on F. A. P. 36 is doubtless due to the use of crushed limestone as coarse aggregate. The sand also is said to have been of better than average quality.

DRAINAGE.—F. A. P. 14 crosses the South St. Vrain creek bottom where natural drainage conditions are poor. Ground water rises close to the surface in the adjacent fields. The new grade line was laid close to the surface of the old road fill which in most places was three to four feet high. Except at the bridge approaches, Stations 12 to 18, the original road fill was raised only a few inches. The original fill was made from borrow pits along each side of the road which should tend to improve drainage conditions. In spite of these drainage provisions the moisture content, in places, exceed the moisture equivalent of the subgrade soil.

F. A. P. 36 continues across the St. Vrain creek bottom to Station 58 where the road rises to higher and more rolling ground where natural drainage conditions are much improved.

F. A. P. 88 traverses rolling upland ground where natural drainage conditions are good. The condition of the pavement is also much improved on this project.

SUBGRADE SOIL.—The subgrade soil is classified as sandy loam or sandy clay in the river bottom. As the road rises to higher ground the percentage of clay increases. The cracking of the pavement on these three projects seems to depend more on drainage conditions than upon the natural character of the soil.

MATERIALS AND CONSTRUCTION DETAILS.—On F. A. P. 14 and 88, the sand and gravel were secured from South St. Vrain creek adjacent to the road. Crushed limestone from the sugar factory at Longmont and a coarse sand were the aggregates used on F. A. P. 36. On each of the projects the materials were stored on the subgrade. As a result numerous clay ball pits were observed in the pavement. The concrete was hand tamped and hand finished in each case. The fills were moderately rolled with a horse-drawn roller.

TRAFFIC.—The surface of the pavement shows considerable wear from Stations 0 to 75 and more or less wear is apparent to Station 107. The classification of the pavement on each of these projects is dependent to a large extent on surface wear.

MAINTENANCE.—Maintenance in general has been satisfactory. Lack of adequate filler in joints and cracks at times has no doubt contributed to the ravel and wear on projects 14 and 36.

COLORADO F. A. P. 283-B

U. S. HIGHWAY 285 BERTHOUD-SOUTH

This project begins in the town of Berthoud and extends toward Longmont a distance of 4.209 miles. Construction was started in August, 1925, and completed in December, 1926.

CLASSIFICATION OF PAVEMENT

The pavement on this project falls essentially in class "B" throughout, with a few slabs in class "C" due to cracks. A pavement survey made in May, 1927, shows 3 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE.—Both the 28-day cylinder strength and the core strength are quite uniform. The latter averages 62 percent greater than the former. The cores were drilled when the concrete was from three to six months old.

DRAINAGE.—The natural drainage conditions are good. Two small streams are crossed. Generous side ditches and ample cross drainage have been provided. There is no indication that ground water is close to the surface.

SUBGRADE SOIL.—The subgrade soil is essentially clay. From 4 to 10 inches of sand, in addition to the 2-inch-sand cushion, was spread on the subgrade and disced into the soil. The effect of this treatment on the lineal shrinkage and moisture equivalent percentages of the soil and on the soil classification is shown in the table.

MATERIALS AND CONSTRUCTION DETAILS.—The coarse aggregate used on this project was mostly crushed Lyons sandstone with some crushed phonolite from Cripple Creek. The fine aggregate was mostly sand from various pits along the Big Thompson river and a smaller quantity from pits at Longmont and Boulder. A central mixing plant was used. The maximum haul was about three miles.

The pavement was hand tamped and finished. All fills were rolled with a 5-ton steam roller and allowed to stand over one winter. After the sand for subgrade treatment was spread and before it was mixed with the subgrade, there was a heavy rain which thoroughly soaked the subgrade. This caused the soil to disc into chunks and prevented the formation of an intimate mixture of sand and soil. The result was a mass of clay chunks with sand seams separating them.

COLORADO F. A. P. 86

U. S. HIGHWAY 285 LOVELAND-SOUTH

This project begins at the south city limits of Loveland and extends southerly 1.347 miles. Construction was started in January and completed in November, 1920.

CLASSIFICATION OF PAVEMENT

The pavement on this project falls in two distinct classes. The section from Stations 0 to 38 in the Big Thompson river bottom has been given the "D" classification on account of extensive surface wear and cracking. The balance of the project which traverses the second bottom of the river has been given the "C" classification on account of less surface wear and less cracking.

The "E" classification at Station 26 is due to settlement and repairs of the approach slabs at the Big Thompson river bridge. The 1926 pavement survey shows 44 percent of the slabs to have been cracked.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—A special road section with extra depth of ditches was used from Station 5 to Station 24.

STRENGTH OF CONCRETE.—The average strength of the cores taken on this project is 642 lbs. or a little over 13 percent less than the average of all projects between Denver and Fort Collins. The difference in classification of the pavement between the north and south ends of the project does not appear to be traceable to any appreciable difference in the strength of the concrete.

DRAINAGE.—The greater part of the project lies across the river bottom, only the beginning and the end rising to higher ground. The presence of rushes in the side ditches is evidence that ground water rises to within a few feet of the surface in the river bottom. The high moisture content as compared with the moisture equivalent of the soil is further evidence that subdrainage is poor. This condition is reflected in the number of cracks in the pavement.

SUBGRADE SOIL.—The soil classification is clay or clay loam throughout except for a stretch of sandy clay near the river.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel came from a bank deposit near the Big Thompson river about two miles west of the town of Loveland. The sand contained some mica and a rather high percentage of silt. The materials were stored on the subgrade prior to use. A small mixer was used and the concrete was hand tamped.

MAINTENANCE.—The only evidence of lack of maintenance on this project is perhaps some additional wear at expansion joints and cracks due to lack of proper amount of filler at times.

COLORADO F. A. P. 221

U. S. HIGHWAY 285 FORT COLLINS-LOVELAND

This project begins at the south end of F. A. P. 139 and extends to the city limits of Loveland, a distance of 4.049 miles. Construction was started in August, 1922, and completed in May, 1924.

CLASSIFICATION OF PAVEMENT

From Station 386-50, the beginning of the project, to Station 520, the pavement is largely class "C" due to wear of surface and at expansion joints with some class "E" and a considerable number of class "D" slabs due to cracks in addition to wear. From Station 520 to the Loveland city limits, the pavement is class "B" with occasional class "C" slabs due to cracks. Twenty-nine percent of the slabs were cracked in 1926.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

STRENGTH OF CONCRETE.—The strength as shown by 24 cores is slightly below the average of the pavements tested on the Denver-Fort Collins road. The average strength from the beginning to Station 520, where the pavement falls in classes "C," "D" and "E" is 4,815 lbs. per sq. in. From Station 520 to the end, where class "B" pavement prevails the average strength is 5,525 lbs. per sq. in. This difference in strength may be due to a change in the source of supply of the sand and gravel. The resident engineer has stated that the materials used on the south end were, in his opinion, better than those on the north end, although both passed the specifications.

DRAINAGE.—The project traverses a slightly rolling country where the natural drainage is good. One small stream and several irrigation canals are crossed. Considerable settlement has occurred adjacent to the bridges over these canals. Aside from these points there is nothing to indicate that poor drainage has contributed to the condition of the pavement, even though the side ditches are shallow in places. From Stations 411 to 416 the road crosses a wet depression on a 3-ft. fill. The stability factor here is no worse than the average on the project, and the pavement condition is average.

SUBGRADE SOIL.—The subgrade soil is clay except one sample which was taken on a rock out-crop near Station 518-50.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel for this job came from the Big Thompson river. The aggregates used from the beginning to Station 520 came from three miles east of the project and were not washed while those used from Station 520 to the Loveland city limits, came from one-half mile west of Loveland and were washed. The latter were better quality than the former, according to a statement by the resident engineer. The pavement classification bears out this statement. Approximately from Stations 440 to 470, low test, slow hardening cement was used. This section was laid rather late in the fall. Traffic was allowed on the pavement after the usual curing period. Also a truck broke through the barricades and ran over the pavement when some of it was only 24 hours old. The badly cracked condition of this section is believed to be due to slow hardening cement, cool weather and early traffic.

A central mixing plant was used, with a maximum haul of one mile. The pavement was hand tamped and finished. The subgrade was not rolled but the fills stood over one winter.

The pavement from approximately Stations 440 to 490 was laid in the fall of 1922, when rather wet weather prevailed. The balance of the pavement was laid in 1923 which was one of the wettest years on record. The subgrade on all work done in 1923 was very wet. In spite of this fact the average stability factor on this project in 1926 was fully up to the average of other projects on the Denver-Fort Collins road.

MAINTENANCE.—The maintenance on this project has been fairly satisfactory. There is, however, some ravel at expansion joints which indicates that this portion of the maintenance has not always been as good as it should have been.

COLORADO F. A. P. 129

U. S. HIGHWAY 285 FORT COLLINS-LOVELAND

This project begins at the south end of F. A. P. 85 and extends south a distance of 4.024 miles toward Loveland. Construction was started in March, 1922, and completed in September, 1923.

CLASSIFICATION OF PAVEMENT

The 1926 survey places the greater percentage of the pavement in class "C." There is a slightly improved section between Stations 320 and 360, and several slabs or groups of slabs throughout the project are in the "D" and "E" classes. Between Stations 220 and 223 several slabs have been given the "E" classification on account of warping and settlement. This section of the pavement is on a fill at the foot of a long hill. It is possible that the uneven settlement at this point is due to excess water accumulated in the sand cushion from infiltration through expansion joints, cracks and gravel shoulders farther up the hill to the south. Thirty-three percent of the slabs were cracked in 1926.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—Shallow side ditches and no provision for lateral drainage of the sand cushion are features which should have had more attention in the design of the road section on this project.

STRENGTH OF CONCRETE.—The average strength of the cores taken on this project is 450 lbs. less than the average for the projects between Denver and Fort Collins.

DRAINAGE.—The project traverses rolling upland country where the topography makes natural drainage conditions good. One small stream, Fossil creek, is crossed near the north end of the project. Ample provisions have been made for transverse drainage. The side ditches are shallow in several places and no provision was made for lateral drainage of the sand cushion.

SUBGRADE SOIL.—The subgrade soil is classified as clay throughout except for two sand rock cuts, Stations 214 to 217 and 224 to 229, and the adjacent fills made of the rock taken from these cuts.

The condition of the pavement does not appear to have been greatly influenced by the quality of the subgrade soil.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel were screened from the Poudre river at points from three to five miles east of the project.

From Stations 174 to 238 and from 280 to 320, the sand and gravel were stockpiled on the subgrade and a traction paver was used. On the balance of the project the materials were stockpiled at a central mixing plant. A great number of clay ball pits are observed in the surface of the pavement where the materials were stockpiled on the subgrade. A mechanical tamper and finisher was used from Stations 355 to 386. The balance of the pavement was hand tamped.

COLORADO F. A. P. 85

U. S. HIGHWAY 285 FORT COLLINS-LOVELAND

This project begins at the south end of F. A. P. 33 and extends south a distance of 1.333 miles. Work was started in April and finished in August, 1921.

Classification of Pavement

The pavement is essentially class "B" with one class "D" and a considerable number of class "C" slabs, due to transverse cracks. Only 13 percent of the slabs on this project were cracked in 1926.

Condition of Pavement as Affected by the Following Factors:

Design.—The design seems to have satisfactorily met the conditions on this project.

Strength of Concrete.—The concrete on this project is somewhat above the average for the Denver-Fort Collins pavement.

Drainage.—This project traverses slightly rolling ground where the natural drainage conditions are good. There are several short bridges over irrigation ditches. The drainage is evidently good at these points as no damage has resulted.

Materials and Construction Details.—The sand and gravel for this project came from the Poudre river north of Fort Collins. They were taken from under water. The sand carried the crusher fines and was quite coarse. The gravel was of good quality. The aggregrates were stored on the grade. The subgrade was rolled with a horse-drawn roller. The pavement was hand tamped and finished.

COLORADO F. A. P. 33

U. S. HIGHWAY 285 FORT COLLINS-LOVELAND

This project begins at the south city limits of Fort Collins and extends south a distance of 1.962 miles. Construction was started in March and completed in November, 1920.

CLASSIFICATION OF PAVEMENT

The 1926 pavement survey shows the pavement to be essentially in classes "C" and "D." The first 3,500 feet of the project south of Fort Collins shows extensive surface wear which places it in class "D." The balance of the project falls in class "C" with a somewhat improved section between Stations 53 and 70. Thirty percent of the slabs showed more or less major cracks in 1926.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—There is no particular evidence of weakness in the design of the pavement on this project. No sand cushion or other subgrade treatment was provided.

STRENGTH OF CONCRETE.—The strength of the concrete is somewhat erratic and below the average of the Fort Collins-Denver road. An insufficient number of cores were taken to show any definite relation between the strength of the concrete and the present condition of the pavement.

DRAINAGE.—The project traverses slightly rolling upland country where natural drainage conditions are good. No streams of any importance are crossed, and ground water is not in evidence at any point. The side ditches are shallow, otherwise ample provision has been made for local drainage.

SUBGRADE SOIL.—The soil is clay throughout.

MATERIALS AND CONSTRUCTION DETAILS.—The sand and gravel came from the Poudre river three miles east of the project. The aggregates were stockpiled in a windrow on the subgrade. The pavement was hand tamped and finished. The pitted condition of the surface of the pavement indicates that considerable dirt was picked up with the aggregates during paving operation.

COLORADO F. A. P. 275-A

U. S. HIGHWAY 85 GANN-CASTLE ROCK

This project begins at the end of F. A. P. 230-B and extends southeasterly toward Castle Rock, a distance of 7.008 miles. Construction was started in July, 1925, and completed in September, 1926.

CLASSIFICATION OF PAVEMENT

The classification of the pavement varies from class "B" to class "F." Near the beginning of the project, from Stations 256 to 268, the poor classification is due to severe scaling caused by the use of calcium chloride in curing the pavement. On this section the surface has scaled to a depth varying from 1/8 to 3/4 of an inch. No cracks have occurred in the scaled slabs up to the time of the pavement survey in May, 1927. Three or four slabs on each side of the bridge at Stations 559 to 560 are badly scaled due to frost action. The poor classification of the pavement on the rest of the project is due to chalky concrete, cracks, scaling, faulting and more or less complete disintegration in places. Portions of several slabs have had to be replaced. Fourteen percent of the pavement slabs were cracked at the time of the pavement survey made in May, 1927.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—The design of the pavement and road sections is not believed to be an important factor in the serious condition of the pavement on this project.

STRENGTH OF CONCRETE.—The concrete on this project has a chalky appearance and is much lower in strength than that on 275-B laid at the same time and under the same climatic and physical conditions. Many of the slabs are badly cracked and portions of several slabs have been taken up and replaced with new concrete. The cause of the low strength of the concrete is a source of much speculation, but is possibly due largely to the character of the fine aggregate. The grading of the coarse aggregate may also have had some influence on the strength.

DRAINAGE.—This project traverses rolling upland country where the natural drainage conditions are good. No evidence exists of ground water approaching the surface at any point. Ample side ditches and cross drainage structures have been provided to care for surface drainage.

SUBGRADE SOIL.—The soil is classified as sand, sandy loam or sandy clay with a few short stretches of clay. The following sections, totaling approximately one mile, were given a four-inch sand treatment, disced in to a depth of eight inches.

Station 265	267-50	Station 417	423-50
" 290	298-50	" 427	428
" 303	317	" 465	468
" 340	348	" 473-50	480
" 407	410		

The present condition of the pavement appears to bear very little, if any, relation to the character of the subgrade soil.

MATERIAL AND CONSTRUCTION DETAILS.—The cement was of the same brand and shipped from the same bin tested stock as that used on F. A. P. 275-B and D. The coarse aggregate was Cripple Creek rock shipped from the same source as that used on F. A. P. 275-B and D.

The fine aggregate seems to have been the principal source of difficulty in securing good concrete on this project. The sand was obtained from two local bank pits very similar in character. One of the pits was located about one mile north of Sedalia, the other near Gann Siding. The sand in both pits was very coarse in texture and contained a brownish clay coating. The sand from the Sedalia pit, employed in the 1925 pavement work, was used without washing. An attempt was made to wash the sand from the Gann pit but the clay content in the finished product usually ran close to 3 percent.

The proportioning plant used on this project consisted of steel bins and batch boxes which measured the sand and gravel very accurately. The coarse aggregate was dumped from the railroad car into a chute from whence it was elevated to the bins. This method offered no opportunity for mixing the material from different cars to improve the grading. A wide variation in the grading of the rock was observed in shipments from day to day.

COLORADO F. A. P. 275-B AND D

U. S. HIGHWAY 85 DENVER-COLORADO SPRINGS

Section B, F. A. P. 275, begins at the end of Section A, about two miles southeast of Sedalia and extends south to Castle Rock, length 5.334 miles. Section D involves an underpass of the D. & R. G. W. Railway and lies within the limits of Section B, length 0.879 miles. Construction was started on Section B in July, 1925, and on Section D in January, 1926, and both projects were completed by the end of 1926.

CLASSIFICATION OF PAVEMENT

The concrete pavement on both Sections B and D is of exceptional quality. Only minor defects such as hair-checks, clay ball pits, chips of wood which accompanied the coarse aggregate and found their way into the concrete, are to be observed. Only seven out of 551 slabs had developed major cracks at the time of the pavement survey made in May, 1927. These seven were mostly at culverts and were caused by settlement of the back fill.

CONDITION OF PAVEMENT AS AFFECTED BY THE FOLLOWING FACTORS:

DESIGN.—The pavement section with thickened edges and center line joint together with sand subgrade treatment, where needed, are believed to be the important factors in the present excellent condition of the pavement.

STRENGTH OF CONCRETE.—While the average strength of the drill cores is quite high, the variation between maximum and minimum strength is wide. The variation in strength of the concrete as shown by the cores or by the field cylinders does not appear to be reflected in the present condition of the pavement.

DRAINAGE.—These projects traverse a rolling upland country where natural drainage conditions are good. Generous side ditches and ample cross drainage structures have been provided. No indication of ground water approaching the surface is apparent at any point on the project.

SUBGRADE SOIL.—The subgrade soil was given a 4-inch sand treatment, disced in, where the moisture equivalent was above 20 percent. From Stations 848 to 865, the subgrade treatment was extended to the full width of the fill. The balance of the treatment was applied under the paved section only.

MATERIALS AND CONSTRUCTION DETAILS.—The coarse aggregate, crushed rock (Phonolite), all came from Cripple Creek. The grading of the rock in different shipments varied quite widely. This was overcome to some extent by stockpiling several carloads at a time at the paving plant and mixing the coarse and fine as the material was withdrawn from the stockpile.

The sand was obtained from two sources. The material used on the south end of the project was shipped from the High Grade Plant at Petersburg, near Denver. The balance of the sand came from a local pit in Plum creek adjacent to the project. Both sands were washed and the finished product in each case was clean and well graded.

The concrete was all mixed at central mixing plants, one located at Castle Rock, the other on a siding about one mile from the north end of the project. The concrete was hauled from the plant to the road in trucks. As a rule, the consistency of the concrete would be represented by a two to three-inch slump. No special devices were used for weighing the aggregates or measuring the water. The concrete was hand tamped and finished.

TABLE 1.—GENERAL DATA ON COLORADO PAVEMENT AND SUBGRADE STUDIES

F. A. Proj. No.	Location	Length Miles	Date Completed	Pavement Classification: Percentage	Classification	Due To	Percentage of Cracked Slabs	Date of Survey
725A	Gann .... Castle Rock	7.008	1926	81.0	B	Minor defects	14	1927
				11.9	C	Cracks	..	....
				2.4	D	Cracks and scaling	..	....
				3.8	E	Bad scaling	..	....
				0.9	F	Replacements	..	....
275B	Sedalia ...... Castle Rock	5.334	1926	99.0	B	Minor defects	1	1927
				1.0	C	Cracks	..	....
275D	Sedalia ...... Castle Rock	0.879	1926	97.6	B	Minor defects	1	1927
				2.4	C	Cracks	..	....
129	Denver ...... Broomfield	4.424	1923	10.1	B	Minor defects	43	1926
				85.0	C	Cracks	..	....
				4.9	D	Cracks, faults, corner breaks	..	....
133	Denver ...... Broomfield	4.223	1923	0.0	B	Minor defects	71	1926
				90.1	C	Cracks	..	....
				8.4	D	Cracks, warping, settlement	..	....
				1.5	E	Cracks, warping, settlement	..	....
222A	Near .... Broomfield	2.737	1923	0.0	B	Minor defects	63	1926
				97.2	C	Cracks	..	....
				2.4	D	Cracks, corner breaks	..	....
				0.4	E	Cracks and settlement	..	....
222B	Near .... Broomfield	1.518	1923	35.4	B	Minor defects	17	1926
				60.9	C	Cracks	..	....
				3.1	D	Corner breaks	..	....
				0.6	E	Corner breaks, spreading settlement	..	....
222C	Broomfield ... Lafayette	2.825	1925	44.2	B	Minor defects	16	1926
				43.6	C	Cracks	..	....
				5.1	D	Heaving, warping, settlement	..	....
				1.1	E	Heaving, warping, settlement	..	....
				6.0	F	Replacements	..	....
281A	Broomfield ... Lafayette	1.249	1925	94.7	B	Minor defects	5	1926
				4.4	C	Cracks	..	....
				0.9	D	Wear, settlement, cracks	..	....
281B	Lafayette .... Longmont	3.068	1925	93.2	B	Minor defects	6	1926
				6.8	C	Cracks	..	....
88	Longmont	1.117	1921	58.2	B	Minor cracks and defects	19	1926
				41.8	C	Wear, ravel	..	....
36	Lafayette .... Longmont	1.182	1922	22.0	C	Wear, ravel	15	1926
				77.5	D	Wear, ravel	..	....
				0.5	E	Settlement	..	....
14	Lafayette .... Longmont	0.504	1920	97.4	D	Wear, ravel	42	1926
				2.6	E	Settlement	..	....
86	Near .... Loveland	1.347	1920	46.5	C	Wear cracks (minor)	44	1926
				49.5	D	Wear, cracks (extensive)	..	....
				4.0	E	Cracks and settlement	..	....
283B	Near .... Berthoud	4.209	1926	96.5	B	Minor defects	3	1927
				3.5	C	Cracks	..	....

TABLE 1.—GENERAL DATA ON COLORADO PAVEMENT AND SUBGRADE STUDIES—Continued

F. A. Proj. No.	Location	Length Miles	Date Completed	Pavement Classification			Percentage of Cracked Slabs	Date of Survey
				Percentage	Classification	Due To		
221	Near Loveland	4.049	1924	31.8	B	Minor defects	29	1926
				60.8	C	Cracks	..	....
				5.6	D	Cracks, wear	..	....
				1.8	E	Cracks, wear	..	....
139	Loveland ..... Fort Collins	4.024	1923	17.2	B	Minor defects	33	1926
				74.1	C	Cracks	..	....
				6.3	D	Cracks, wear	..	....
				2.4	E	Warping, settlement	..	....
85	Fort Collins.. Loveland	1.333	1921	80.1	B	Minor defects	13	1926
				19.2	C	Cracks	..	....
				0.7	D	Cracks and settlement	..	....
33	Near .... Fort Collins	1.962	1920	11.1	B	Minor defects	30	1926
				56.0	C	Cracks	..	....
				32.6	D	Extensive wear	..	....
				0.3	E	Wear and scaling	..	....
Hewitt's	Denver .... Brighton	1.70	1918	3.5	B	Minor defects	81	1925
				28.4	C	Cracks	..	....
				50.6	D	Wear	..	....
				15.9	E	Excessive wear	..	....
				1.6	F	Replaced or repaired	..	....
10	Denver ...... Brighton	1.79	1920	9.6	B	Minor defects	60	1925
				74.6	C	Wear	..	....
				15.5	D	Ravel	..	....
				0.3	E	Minor breaks	..	....
32	Denver ...... Brighton	5.74	1921	73.1	B	Minor defects	50	1925
				18.3	C	Wear, cracks	..	....
				8.0	D	Corner breaks, cracks, wear	..	....
				0.6	E	Settlement, extensive wear	..	....
89	Denver ...... Brighton	4.40	1921	62.0	B	Minor defects	49	1925
				33.4	C	Cracks	..	....
				4.6	D	Corner breaks	..	....
148	Near .... Brighton	4.77	1922	56.6	B	Minor defects	37	1925
				41.2	C	Wear	..	....
				2.2	D	Corner breaks	..	....
226A	Fort Lupton..	8.22	1923	28.1	B	Minor defects	27	1925
				46.5	C	Wear, cracks	..	....
				25.4	D	Corner breaks, cracks	..	....
35	Platteville ...	1.19	1920	29.3	B	Slight wear	30	1925
				45.3	C	Wear, ravel	..	....
				25.4	D	Wear, ravel	..	....
226B	Platteville ...	2.86	1924	0.6	A	Perfect pavement	27	1925
				82.0	B	Minor defects	..	....
				15.5	C	Cracks	..	....
				1.9	D	Cracks, corner breaks	..	....
226D	Platteville ...	1.16	1925	98.8	A	Perfect pavement	2	1925
				1.2	B	Minor defects	..	....
226C	Platteville ... Greeley	10.73	1924	96.1	B	Minor defects	12	1925
				3.9	C	Transverse cracks	..	....
Golden Road	Denver ...... Golden	8.80	....	1.7	B	Minor defects	81	1925
				59.3	C	Cracks	..	....
				32.6	D	Cracks, wear	..	....
				6.0	E	Replacement	..	....
				0.4	F	Major replacements	..	....

TABLE 1.—GENERAL DATA ON COLORADO PAVEMENT AND SUBGRADE STUDIES—Continued

F. A. Proj. No.	Location	Length Miles	Date Completed	Pavement Classification			Percentage of Cracked Slabs	Date of Survey
				Percentage	Classification	Due To		
131	Denver ...... Aurora	0.83	1922	87.3	B	Minor defects	14	1925
				11.3	C	Transverse cracks	..	....
				1.4	D	Corner breaks	..	....
31	Denver ...... Aurora	1.17	1920	55.8	B	Minor defects	59	1925
				41.0	C	Transerve cracks	..	....
				3.2	D	Corner breaks	..	....

TABLE 1.—As it has been thought to be not feasible to include all the graphs in this publication, the percentage of the various classes of pavement have been taken from the graphs and are given in Table 1, along with other data of a general nature.

TABLE 2.—PAVEMENT CLASSIFICATION SUMMATION, COLORADO PAVEMENT AND SUBGRADE STUDIES, 1925-1926 SURVEY

F. A. Project No.	Length Miles	Amount in Each Class (Miles)					
		A	B	C	D	E	F
275A	7.008	.....	5.676	0.834	0.168	0.266	0.064
275B	5.334	.....	5.281	0.053	.....	.....	.....
275D	0.879	.....	0.858	0.021	.....	.....	.....
129	4.424	.....	0.447	3.760	0.217	.....	.....
133	4.223	.....	.....	3.785	0.355	0.063	.....
222A	2.737	.....	.....	2.660	0.066	0.011	.....
222B	1.518	.....	0.537	0.924	0.048	0.009	.....
222C	2.825	.....	1.249	1.232	0.144	0.030	0.170
281A	1.249	.....	1.183	0.055	0.011	.....	.....
281B	3.068	.....	2.859	0.209	.....	.....	.....
88	1.117	.....	0.650	0.467	.....	.....	.....
36	1.182	.....	.....	0.260	0.916	0.006	.....
14	0.504	.....	.....	.....	0.491	0.013	.....
86	1.347	.....	.....	0.626	0.667	0.054	.....
283B	4.209	.....	4.062	0.147	.....	.....	.....
221	4.049	.....	1.288	2.462	0.227	0.072	.....
139	4.024	.....	0.692	2.982	0.254	0.096	.....
85	1.333	.....	1.068	0.256	0.009	.....	.....
33	1.962	.....	0.218	1.099	0.640	0.005	.....
Hewitt's	1.70	.....	0.060	0.483	0.860	0.270	0.027
10	1.79	.....	0.172	1.335	0.277	0.006	.....
32	5.74	.....	4.196	1.050	0.459	0.035	.....
89	4.40	.....	2.728	1.470	0.202	.....	.....
148	4.77	.....	2.700	1.965	0.105	.....	.....
226A	8.22	.....	2.310	3.821	2.089	.....	.....
35	1.19	.....	0.349	0.539	0.302	.....	.....
226B	2.86	0.017	2.345	0.443	0.055	.....	.....
226D	1.16	1.146	0.014	.....	.....	.....	.....
226C	10.73	.....	10.312	0.418	.....	.....	.....
Golden Road	8.80	.....	0.150	5.218	2.869	0.528	0.035
131	0.83	.....	0.724	0.094	0.012	.....	.....
31	1.17	.....	0.653	0.480	0.037	.....	.....
Total	106.352	1.163	52.781	38.448	11.480	1.464	0.296
Percentages	100.00	1.10	49.63	36.81	10.80	1.38	0.28

TABLE 2.—This table gives a summation of the pavement classification for all projects included in this study.

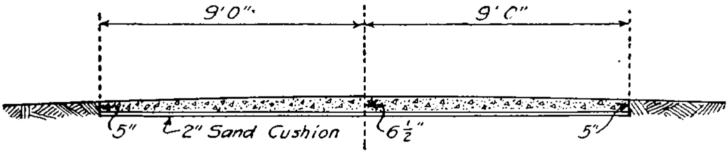
TABLE 3.—PAVEMENT AND ROAD SECTIONS, COLORADO PAVEMENT AND SUBGRADE STUDIES

F. A. Project No.	Pvt. Sec.	Sand Cush.	Subgr. Treatmt.	Shoulders			Ditches	Pavement Thickness on Center Line As Determined by Cores		
				Material	Width	Thickness	Depth	Aver.	Max.	Min.
275A	C	2″	Partly	Gravel	4′	3″	15″	6.55″	9″	5½″
275B	C	2″	"	"	4′	3″	15″	6.66″	7½″	5½″
275D	C	2″	"	"	4′	3″	15″	6.92″	7½″	6¼″
129	B	2″	None	"	4′	6″–4″	15″	6.86″	8″	6″
133	B	2″	"	"	4′	6″–4″	15″	7.20″	9″	6″
222A	B	2″	"	"	4′	6″–4″	15″	7.54″	8½″	6″
222B	B	2″	"	"	4′	6″–4″	15″	7.00″	7½″	6½″
222C	B	2″	"	"	4′	6″–4″	15″	7.04″	8″	6½″
281A	C	2″	"	"	4′	3″	15″	6.00″	7″	5½″
281B	C	2″	"	"	4′	3″	15″	6.25″	7″	5¾″
88	B	2″	"	"	4′	2″	15″	7.44″	8″	7¼″
36	B	None	"	"	4′	2″..	15″	7.94″	8½″	7½″
14	B	"	"	"	4′	2″	15″	7.25″	8″	6¾″
283B	C	2″	Yes	"	4′	3″	15″	6.81″	7¼″	6″
86	B	None	None	"	4′	2″	1′–2′	6.85″	7½″	6″
221	B	2″	"	"	4′	6″–4″	15″	6.97″	8″	5″
139	B	2″	"	"	4′	6″–4″	15″	7.24″	9″	6″
85	B	2″	"	"	4′	2″	15″	6.72″	7″	6″
33	B	None	"	"	4′	2″	15″	6.50″	7½″	5½″
Hewitt's	A	"	"	"	4′	2″	15″	7.56″	9″	6½″
10	B	"	"	"	4′	2″	15″	7.63″	8″	7″
32	B	"	"	"	4′	2″	15″	7.56″	8½″	6″
89	B	"	"	"	4′	2″	15″	7.90″	9″	7″
148	B	"	"	"	4′	6″–4″	15″	8.09″	8½″	7″
226A	B	2″	"	"	4′	6″–4″	15″	7.57″	8″	6½″
35	B	2″	"	"	4′	2″	15″	8.12″	8½″	8″
226B	B	2″	"	"	4′	6″–4″	15″	6.00″	6″	6″
226D	C	2″	"	"	4′	6″–4″	15″	7.36″	8″	6½″
226C	D	None	"	"	4′	3″	15″	6.88″	8″	6″
Golden Road	A	"	"	"	4′	...	...	6.63″	9″	5½″
131	B	2″	"	"	4′	6″–4″	15″	...	..	..
31	B	None	"	"	4′	2″	15″	7.95″	8½″	7½″

TABLE 3.—This table summarizes the pavement and road sections used on the projects involved in this study. A sketch of the pavement sections follows this table.

Details of Concrete Slabs used on Projects included in Pavement and Subgrade Studies.

Section "A"



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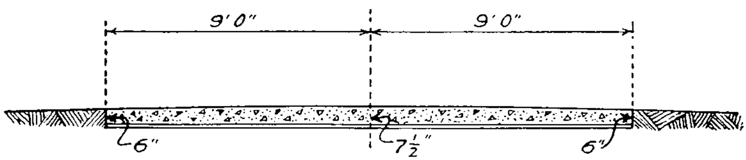

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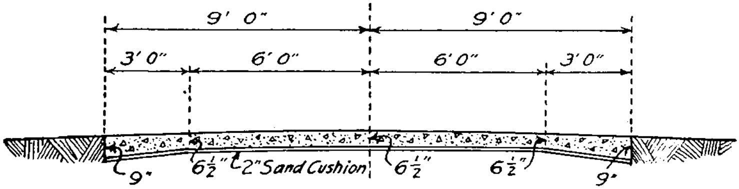

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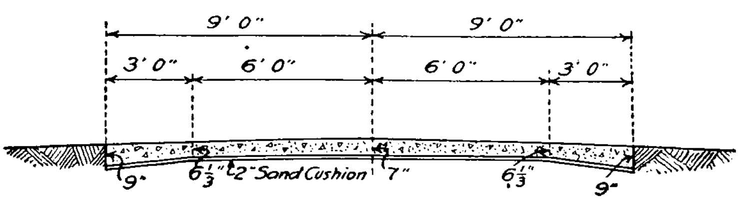

TABLE 4.—COMPRESSIVE STRENGTH OF CONCRETE, COLORADO PAVEMENT AND SUBGRADE STUDIES

DENVER-COLORADO SPRINGS ROAD

F. A. Project No.	Drill Cores				6″ × 12″ Field Cylinders			
	No.	Strength			No.	1:2:3 Mix 28 Day		
		Aver.	Max.	Min.		Aver.	Max.	Min.
275A	57	3825	6770	2480	160	2495	3780	1015
275B	23	6250	7770	4570	88	3214	4595	1700
275D	3	5510	6600	4560	81	3012	4680	1665

DENVER-FORT COLLINS ROAD

129	15	5312	7250	4350	....	....	....	....
133	28	5370	7040	3890	....	....	....	....
222A	15	5214	6100	4255	....	....	....	....
222B	3	5677	6235	5085	....	....	....	....
222C	13	5170	5820	3400	....	....	....	....
281A	8	5618	6335	4925	....	....	....	....
281B	5	6034	6170	5675	....	....	....	....
88	4	4598	5305	4270	....	....	....	....
36	9	6362	7050	5580	....	....	....	....
14	5	5116	5230	4225	....	....	....	....
283B	21	5087	5935	4500	135	3147	4135	2010
86	11	4687	6550	3805	....	....	....	....
221	24	5058	6560	3530	....	....	....	....
139	23	4875	6170	3600	....	....	....	....
85	7	5600	6270	4815	....	....	....	....
33	7	5346	6295	4225	....	....	....	....
Average (weighted)	..	5323	....	....	....	....	....	....

DENVER-GREELEY ROAD

St. Proj.								
Hewitt's	8	3830	5010	2520	....	....	....	....
10	7	4750	5450	3900	....	....	....	....
32	26	4540	5660	3580	....	....	....	....
89	20	4440	5100	3250	....	....	....	....
148	22	4540	5740	3080	....	....	....	....
226A	28	4280	5500	3000	....	....	....	....
35	4	5250	5700	4700	....	....	....	....
226B	11	4750	5900	3900	....	....	....	....
226D	2	4850	5130	4570	....	....	....	....
226C	38	5050	6620	3800	....	....	....	....
Ave. (Weighted)	..	4628	....	....	....	....	....	....

DENVER-GOLDEN ROAD

Golden Road	39	5250	8150	2875	....	....	....	....

DENVER-EAST ROAD

131	4	4340	5050	4070	....	....	....	....
31	5	3825	4920	2930	....	....	....	....

TABLE 4.—In Table 4, the compressive strength of the concrete for all projects have been assembled by highways, and the averages of the project averages computed. Field cylinder data taken during construction have been given where available. Systematic testing of field cylinders was not started until 1926, hence the lack of this data on all projects constructed before that time.

FINE AGGREGATE.—River sand of granitic origin was used as fine aggregate on all projects except 275-A where granitic bank sand was used.

COARSE AGGREGATE.—The coarse aggregate used on the various projects was as follows:

F. A. P.	MATERIAL USED
275-A, 275-B, 275-D	Crushed phonolite from mine dumps at Cripple Creek.
Golden Road	Crushed basalt from near Golden.
36	Crushed limestone (Sugar Factory Spalls)
283-B	Crushed Lyons Sandstone.
All other projects	Granitic River Gravel.

TABLE 5.—In this table, three studies of the core strength data have been made; namely, according to the time when the pavement was constructed, its geographical location, and the method of field storage of the aggregate. The higher strengths shown by the younger pavements may be explained by the fact that materials inspection and control, construction methods and general knowledge of concrete have all been improved during the period covered by pavement construction in Colorado. Better concrete may, and now is, being produced in most cases.

The strength of the concrete on the Denver-Fort Collins road is 15 percent higher than that on the Denver-Greeley. The reasons for this are not apparent.

No definite conclusions can be drawn from the data on materials storage. Other factors have doubtless contributed to the general result and it is doubtful if the differences shown are especially significant. It is hoped that additional information along this line may be gathered in the future.

TABLE 5.—COMPRESSIVE STRENGTH OF CONCRETE, COLORADO PAVEMENT AND SUBGRADE STUDIES

F. A. Project No.	Year Pavement Was Constructed							Road, Denver to			Materials Storage		
												Central	
	1920	1921	1922	1923	1924	1925	1926	Greeley	Fort Collins	Aurora	On Subg.	Mix	Prop.
275A							3825						3825
275B							6250					6250	
275D							5510					5510	
129			5312						5312				5312
133			5370						5370				5370
222A			5214						5214				5214
222B				5677					5677			5677	
222C					5170				5170				5170
281A					5618				5618		5618		
281B						6034			6034		6034		
88		4598							4598		4598		
36			6362						6362		6362		
14	5116								5116		5116		
283B							5087		5087			5087	
86	4687								4687		4687		
221				5058					5058			5058	
139				4875					4875			4875	
85		5600							5600		5600		
33	5346								5346		5346		
Hewitt's	3830†							3830			3830		
10	4750							4750			4750		
32		4540						4540			4540		
89		4440						4440			4440		
148			4540					4540				4540	
226A				4280				4280			4280		
35	5250							5250			5250		
226B					4750			4750				4750	
226D						4850		4850				4850	
226C					5050			5050				5050	
Golden	5250*										5250		
31	3825									3825	3825		
131			4340							4340	4340		
Average	4687	4795	5190	4973	5147	5442	5168	4628	5323	4082	4933	5165	4978
			4955 (without #36)				5616		Without 275A poor sand				5267
				(Limestone Aggregate									

* Laid in 1917.
† Laid in 1918.

TABLE 6.—SUBGRADE SOIL CHARACTERISTICS, COLORADO PAVEMENT AND SUBGRADE STUDIES

F. A. Project No.	General Soil Class	Clay			Moisture Equiv.			Lineal Shrinkage			Vertical Capil.			Moisture Content			No.
		Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Smp.
275A	S'd Lim.	17.4	49	2	11.8	31.0	3.0	3.8	13.5	0.0	27.7	40.1	16.1	10.4	20.2	3.7	57
275B	S'd Clay	18.9	34	3	12.1	22.3	2.2	3.4	7.9	0.0	20.3	29.7	8.6	11.8	18.2	4.3	19
275D	S'd Lim.	19.7	35	10	13.7	20.6	7.4	3.9	6.3	0.8	28.4	39.1	22.0	12.8	20.7	7.8	6
129	Clay	33.1	61	5	21.1	36.8	5.0	6.5	10.7	0.0	24.4	33.9	10.9	16.3	22.7	2.6	16
133	"	40.5	56	28	25.7	34.3	16.6	8.8	13.0	6.3	28.9	36.5	21.4	18.7	26.2	13.2	28
222A	"	44.4	55	38	26.8	31.5	18.8	9.0	11.0	7.2	28.1	32.9	21.3	19.4	24.5	12.9	14
222B	"	39.0	50	23	21.2	25.8	13.8	7.6	9.2	4.7	26.9	25.7	18.3	17.2	20.0	12.4	3
222C	"	44.5	71	30	25.6	37.5	19.5	8.6	10.8	4.5	28.5	33.5	25.0	17.2	26.1	13.7	19
281A	"	26.7	43	18	15.3	29.7	8.3	6.1	9.5	2.8	30.0	32.4	25.8	11.7	15.4	8.4	6
281B	"	36.2	51	17	19.0	24.6	10.7	6.1	8.0	2.7	29.9	38.3	27.4	13.4	18.6	7.6	5
88	"	38.5	53	30	20.8	23.2	17.6	7.1	7.9	6.3	26.5	29.0	23.0	17.2	19.2	12.7	4
36	"	26.8	39	15	17.3	26.7	9.8	5.0	9.5	2.2	25.2	33.1	20.9	15.0	19.2	6.7	8
14	"	22.2	32	17	15.2	17.7	12.8	3.0	5.1	0.0	20.1	21.1	19.2	14.1	17.5	12.4	5
283B	"	46.0	59	24	22.3	27.3	10.7	7.8	8.9	4.5	28.9	33.4	18.3	17.0	21.3	7.8	21
221	"	46.2	61	20	25.0	30.7	9.8	7.7	9.8	2.7	30.2	32.7	27.0	19.3	28.0	11.7	24
139	"	43.4	67	9	23.1	28.4	10.8	7.1	9.5	1.3	29.6	36.2	21.4	17.5	22.3	12.0	22
85	"	42.6	47	38	21.3	23.7	18.7	7.6	8.1	7.1	29.3	33.2	27.1	15.8	17.4	12.7	7
33	"	46.4	55	38	24.3	29.5	19.9	8.2	9.8	6.4	30.5	34.4	27.4	18.7	23.5	12.4	7
Hewitt	S'd Lim.	15.4	43	6	10.7	26.5	4.0	2.8	10.0	0.3	22.9	32.6	10.6	No	data		8
10	" "	13.1	18	12	15.4	21.0	12.1	2.9	5.5	1.0	22.5	28.5	21.2	7.5	10.8	5.5	7
32	" "	18.7	35	7	19.6	31.8	12.7	3.7	7.0	0.5	25.0	28.7	19.2	9.5	16.2	5.5	26
89	Clay	30.5	48	9	19.3	30.6	6.0	6.1	11.0	0.9	24.7	36.1	14.2	13.1	20.5	6.5	20
148	S'd Lim.	20.5	51	1	13.0	32.1	1.4	3.7	8.9	0.0	19.2	30.8	10.6	10.2	18.3	0.9	22
226A	" "	19.1	30	5	12.5	21.3	3.0	3.7	7.5	0.3	20.1	25.0	10.8	10.9	15.5	3.9	28
35	Cl. Lim.	29.7	36	24	15.6	19.3	13.1	4.9	6.6	3.4	19.1	22.1	16.2	12.7	14.9	10.3	4
226B	S'd Lim.	17.0	24	9	11.2	16.9	5.2	2.6	4.3	0.5	17.9	21.5	14.2	9.5	12.7	4.5	11
226D	" "	14.5	24	9	16.4	19.5	14.3	2.3	4.3	0.9	20.8	23.3	19.0	7.3	12.2	4.5	6
226C	" "	11.7	26	5	8.3	19.7	4.5	1.4	5.2	0.0	22.5	26.4	17.2	7.4	12.4	4.6	38
Golden Road	Clay	44.5	64	18	31.7	41.8	12.5	9.2	12.0	4.3	33.5	47.2	23.4	21.4	33.6	11.5	39
131	"	34.0	38	29	21.5	23.9	20.3	6.9	7.9	5.9	27.9	30.6	23.7	No	data		4
31	"	37.5	43	32	27.3	30.0	23.2	7.9	9.9	6.9	29.9	35.8	25.4	No	data		6

TABLE 6.—This table is believed to be useful in showing the general characteristics and types of soils encountered on the various projects. A more detailed study of the relations of moisture content to moisture equivalent percentages will be found in Table 7. It will be seen that the soils on the Denver-Colorado Springs road are the lightest for the roads included in this investigation. The Denver-Greeley road has the next heavier soil while those on the Denver-Golden and the Denver-Fort Collins are the heaviest of all.

TABLE 7.—This table shows the results of detailed studies into the relation between moisture equivalent and moisture content, both for center line and shoulder samples. A term has been used here which is new to the writers. The moisture equivalent percentage divided by the moisture content percentage has been designated "Stability Factor." Its significance is similar to that of the term "Factor of Safety" used in engineering design, in that the higher the Stability Factor, all other things being equal, the more stable the soil and the higher its bearing power. This is not true of the term "Stability Ratio," which is the reciprocal of the Stability Factor. Consequently, the higher the Stability Ratio, the less stable the soil. It seems that clarity of thought is aided by the use of a term whose value increases as the stability of the soil increases.

In general, shoulder samples have a higher stability factor than those taken from on center line from under the pavement. This indicates that in general the soil moisture movements are from under the pavement toward the shoulders and side ditches.

Samples on the Denver-Fort Collins and the Denver-Colorado Springs roads were taken in 1926, which was about an average season as regards rainfall. The Denver-Greeley and the Denver-Golden roads were sampled in 1925, which was a dry year. The difference in stability factors may be explained in this way. The stability factors of those sampled in 1925 were very much higher than those in 1926, regardless of the type of soil encountered. This is in general what might be expected but the effect of dry weather on the moisture content under the pavement is, perhaps, more than would be expected. The stability factors of the lighter soils sampled in 1926 is not much above one, while those of the clay soils sampled the same year are somewhat higher. This may be due to the fact that water penetrates a light, porous soil much more readily than a clay soil, and that rains during 1926 were rather frequent.

TABLE 7.—COMPARATIVE SUBGRADE SOIL DATA, CENTERLINE VS. SHOULDER SAMPLES, COLORADO PAVEMENT AND SUBGRADE STUDIES

DENVER-COLORADO SPRINGS ROAD

F. A. Project No.	Percentage				Stability Factor		Number of Samples
	Av. Moisture Equivalent		Av. Moisture Content				
	C. L.	Shoulder	C. L.	Shoulder	C. L.	Shoulder	
275A	11.8	11.9	10.4	10.6	1.14	1.12	57
275B	12.1	11.6	11.8	10.5	1.03	1.11	19
275D	13.7	12.2	12.8	11.8	1.07	1.03	6
Averages	...	...	...	...	1.08	1.09	..

DENVER-FORT COLLINS ROAD

129	21.1	20.5	16.3	16.6	1.29	1.24	16
133	25.7	23.2	18.7	14.8	1.37	1.57	28
222A	26.8	25.5	19.4	17.7	1.38	1.44	14
222B	21.2	26.8	17.2	19.0	1.23	1.41	3
222C	25.6	22.7	17.2	15.9	1.23	1.43	16
281A	15.3	18.6	11.7	14.3	1.31	1.30	8
281B	19.0	17.2	13.4	11.8	1.42	1.46	5
88	20.8	21.2	17.2	16.2	1.21	1.31	4
36	17.3	15.2	15.0	15.5	1.15	0.98	9
14	15.2	17.1	14.1	14.6	1.08	1.17	5
	Treated		Treated		Treated		
283B	12.8	22.3	12.9	15.8	0.99	1.41	21
283B*	22.3	...	17.0	...	1.31	...	21
86	18.3	17.5	16.7	14.7	1.10	1.19	11
221	25.0	23.6	19.3	18.1	1.30	1.30	24
139	23.1	22.7	17.5	16.4	1.31	1.38	24
85	21.3	21.0	15.8	14.9	1.35	1.41	7
33	24.3	23.4	18.7	18.4	1.30	1.27	7
Averages	...	...	...	...	1.25	1.33	..

* Samples below treated soil.

DENVER-GREELEY ROAD

Hewitt's	10.7	15.1	...	...	...	...	7
10	15.4	16.3	7.5	8.6	2.05	1.89	7
32	19.6	18.0	9.5	11.0	2.06	1.64	26
89	19.3	25.9	13.1	12.0	1.47	2.16	20
148	13.0	14.2	10.2	7.1	1.28	2.00	23
226A	12.5	15.4	10.9	8.5	1.15	1.81	29
35	15.6	17.8	12.7	7.8	1.22	2.28	4
226B	11.2	14.2	9.5	9.3	1.18	1.53	7
226D	16.4	16.2	7.3	8.0	2.25	2.03	6
226C	8.3	15.0	7.4	8.3	1.12	1.81	38
Averages	...	...	...	...	1.53	1.91	..

DENVER-GOLDEN ROAD

Golden Road...	31.7	32.2	21.4	20.0	1.48	1.61	39

DENVER-EAST ROAD

31	29.9	31.8	...	...	...	...	6
131	21.5	28.2	...	...	...	...	4

TABLE 8.—TRAFFIC DATA, COLORADO HIGHWAY DEPARTMENT—1925 CENSUS, COLORADO PAVEMENT AND SUBGRADE STUDIES

F. A. Project No.	Near Town	Total Traffic Per Day	Percentage		Remarks
			Trucks	Pass. Bus.	
275A	Sedalia	2000	..	..	
275B	Castle Rock	1800	..	..	
275D	" "	1800	..	..	
129	Denver	3113	12	0.6	
133	"	2421*	12	0.6	
222A	Broomfield	1729*	12	0.6	Probably somewhat greater than this
222B	"	1729*	12	0.5	
222C	"	1729*	12	0.5	
281A	"	1729*	12	0.5	
281B	Longmont	2720*	12	0.5	Probably somewhat less than this
88	"	2720*	12	0.5	
36	"	2720*	12	0.5	
14	"	2720*	12	0.5	
283B	Berthoud	1516*	12	0.5	
86	Loveland	1910*	11	0.6	
221	"	No reliabl	e data av	ailable	
139	Fort Collins	904*	11	0.6	
85	"	1200–1500	11	0.6	
33	"	1809	10.9	0.6	
St. Proj. Hewitt's	Denver	3677	22	..	
10	"	3677	22	..	
32	"	3000*	..	..	
89		.....	..	..	
148	Brighton	2407 South	20*	..	
	..	3208 North	..	..	
226A	Fort Lupton	2005 South	..	..	Heavy steel tired vehicles, north
		1332 North	..	..	
35	Platteville	1389	..	..	
226B	"	1389 South	..	..	
		1267 North	..	..	
226D	"	1328*	..	..	Traffic north and south of Platteville averaged
226C	"	1267	..	..	
	La Salle	1079	..	..	
Golden Road	Denver	3442	13.6	0.5	
131	"	No data av	ailable		
31	"	No data av	ailable		

* Estimated

TABLE 8.—In most cases, traffic counts are not available immediately on the projects studied. In such cases a traffic estimate has been made, based on interpolation of data at the nearest observation points.

GENERAL DISCUSSION

CRACKING, WARPING, HEAVING AND FAULTING

The causes of these pavement defects are believed to be many. The following discussion deals with several possible causes. It is not claimed to be complete, neither does the information available at this time permit definite conclusions to be drawn in all cases.

The defects mentioned are evidently due to unequal subgrade movements. The problem is to determine the causes of these movements. The factors dealt with in the following discussion may have acted singly or jointly to produce any particular failure, depending on local conditions.

SOILS.—The soils investigated, of themselves, are believed to be only the indirect causes of failures. Pavements with a very low percentage of cracked slabs rest upon some of our worst clay soils, which are, however, well drained. Others, on soils which are naturally better, but poorly drained, are badly cracked.

HAIR-CHECKING.—A pavement condition survey made of three projects soon after completion has permitted a study of hair-checking to be made. On these projects, it was found that hair-checking increased the formation of major cracks about 50 percent. This fact indicates the importance of research to determine the causes and means of preventing this defect.

A brief discussion of the possible causes of hair-checks may not be amiss at this time. They are doubtless the result of surface tension set up in the pavement before the concrete has had time to develop sufficient strength to withstand that tension. Surface tension in turn may possibly be caused by several things. A few of those which have been suggested are listed as follows:

1. Dry, hot, windy weather, causing rapid evaporation.
2. A dry subgrade.
3. Uneven swelling or shrinkage of the subgrade.
4. Dry and porous aggregates.
5. Too much clay or silt in the aggregates. (Clay has a high shrinkage factor when moisture is withdrawn.)
6. Too fine grinding of the cement.
7. Too much tamping, thus forming a laitance of cement and other fine particles at the surface of the pavement.
8. Excessive evaporation causing a rapid reduction in temperature.

FROST ACTION.—Frost action is also doubtless a cause of the defects under discussion. The type of soil and the amount of moisture present are possible factors affecting frost action. Chirikov and Maligin have found that there was a movement of water from lower strata to higher strata during the freezing of the soil. That under these conditions, there was a dry stratum under the moist surface strata, and that the movement of soil moisture during the freezing of the soil took place in the form of vapor. The exact effect which this movement of soil vapor and the surface concentration of moisture has on heaving is not definitely known. This subject should be the object of special investigations.

Certain experimenters have stated that capillary moisture is expelled from the soil during freezing and that an ice layer may be formed under the pavement. The use of a well-drained sand blanket has been suggested where this is likely to occur.

SLOW HARDENING.—In certain cases where the pavement was laid late in the fall, serious cracking occurred soon after it was thrown open to traffic. This is believed to be due to cool weather which retarded the hardening of the concrete. Under such conditions, the curing period should be longer than during warmer weather.

WEAR OF PAVEMENT VS. AGE OF PAVEMENT AND AMOUNT AND CHARACTER OF TRAFFIC

It is perhaps significant to state here that all of the older projects were laid adjacent to the cities and towns, or near the centers of population, hence they have been subjected to the heaviest traffic. Construction in later years has progressed outward from these centers of population. The eight projects built during the year 1920 or prior thereto all show more or less wear on the surface. The most serious wear is on the projects adjacent to the city of Denver, on the Golden road, and on the Denver-Greeley road. Some wear is apparent on projects from Denver east through Aurora. Since 1920, surface wear has been about in proportion to the age of the projects. A few notable exceptions to this rule are to be observed.

Projects in the vicinity of the sugar factories at Brighton and Fort Lupton and their outlying beet dumps all show abnormal wear due to the action of heavily laden, steel-tired beet traffic.

STRENGTH OF CONCRETE VS. AGE, WEAR, AND CRACKS

Table 5 shows a gradual improvement in the quality of the pavements laid from year to year. This is doubtless due to the use of better materials and to improved methods of construction, and proportioning and handling materials.

The average strength of the concrete on all of the projects is approximately 5,000 lbs. per sq. in. The maximum average strength for any one project is 6,362 lbs., and the minimum, 3,825 lbs. per sq. in. There is no apparent relation at this time between the strength of the concrete and the amount of wear or number of cracks formed in the payment.

There appears to be considerable increase in the strength of the concrete on the projects where crushed rock was used as the coarse aggregate over those where gravel was used.

SUBGRADE SOILS

The soil data gathered and compiled in this series of studies is believed to be reliable. The amount of moisture present in the soil at the time the samples were secured, however, is not believed to be truly representative, in all cases, of the conditions under which failures in the form of cracks, warping, heaving and settlement have taken place.

Abundant evidence exists to the effect that the amount of moisture present is an important factor in determining the bearing power of soils. The necessity for adequate drainage of the subgrade, therefore, can not be too strongly emphasized. The road sections used on many of the projects appear to have been faulty in that no provision was made for lateral drainage of the sand cushion. Evidence has been found in numerous places where water, finding its way into the sand cushion through expansion joints, cracks and the gravel shoulders, and possibly other sources, has followed down grade and been concentrated at the foot of slopes and in low places in the grade line. Much of the moisture thus concentrated eventually finds its way into the subgrade, thereby reducing its bearing power and often causing failure of the pavement.

SOIL TESTS

A review of the soil tests show that the character of the soils in this region varies from sand to very stiff, plastic clays. The general run of soils on the Denver-Greeley road, which follows down the South Platte river bottom, is sandy loam while that on the Denver-Fort Collins road is clay.

On all classes of soils there has been a close relation between the clay content and the moisture equivalent and lineal shrinkage factors. The vertical capillarity test which was recommended and which has been conducted on all samples thus far has not shown the same close relation to the clay content and its value in determining the quality of the subgrade soil is questionable.

COMPRESSIVE STRENGTH VS. ABSORPTION PERCENTAGE

Studies have been made of all cores drilled for this investigation. The cores were grouped according to their absorption percentages with a class interval of 0.1 percent and the average core strength of the 28 groups obtained. These were plotted as ordinates against absorption percentages as abscissae. The curves obtained are shown in Fig. 12. The trend is plainly seen. It is evident that conditions which operate to produce concrete having high absorption also tend to cause the concrete to have lower strength.

The fact was first noticed in a study of data on cores drilled in 1925. In order to check this conclusion, the cores drilled in 1926 were studied separately with the same result.

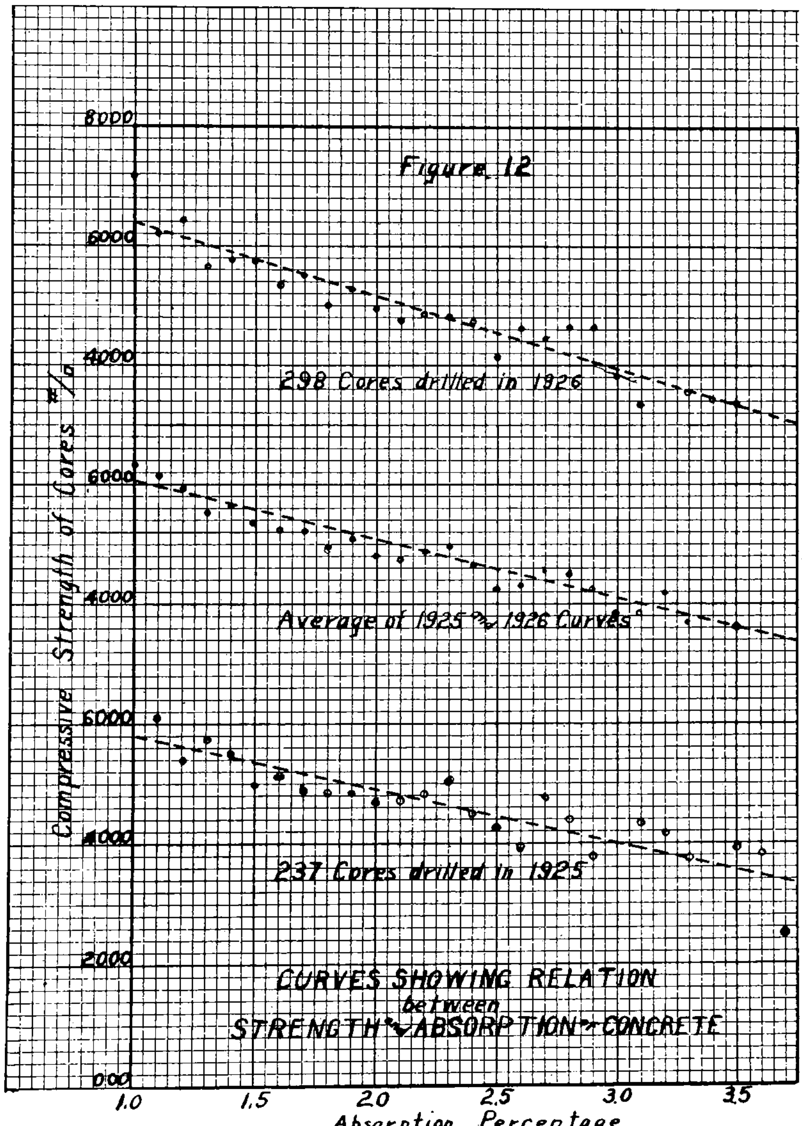

Figure 13.—Graph showing relation between compressive strength and absorption percentage of concrete.

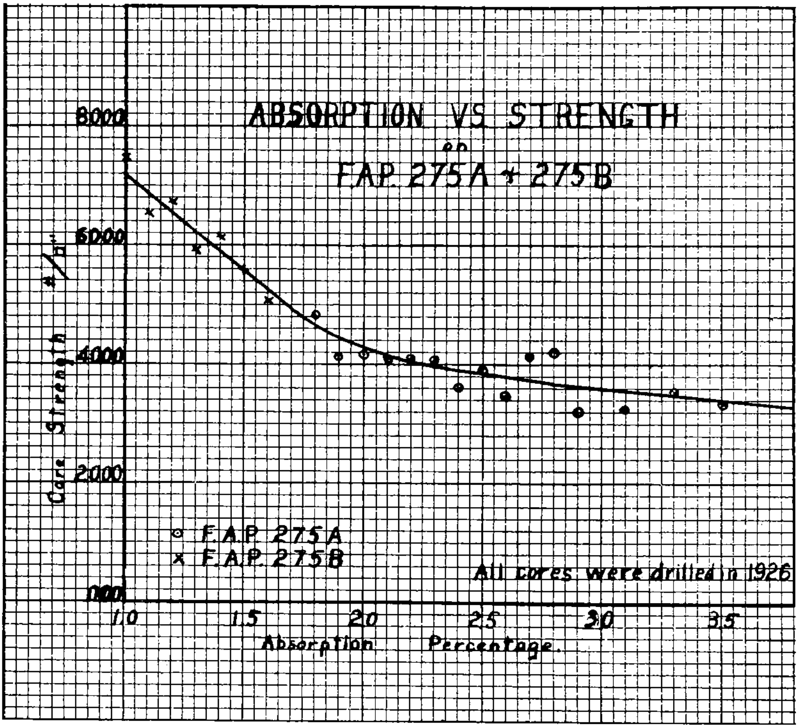

Figure 14.—Graph showing relation between compressive strength and absorption percentage of concrete on F. A. P. 275 A and 275 B.

CONCLUSIONS

1. Sand cushions and granular layers of subgrade treatment should be provided with means of lateral drainage.

2. Hair-checks are a source of a weakness which is apt to result in further deterioration of the pavement.

3. Cracks in the pavement may result from various causes but are more closely associated with clay soils having a high moisture content.

4. The range in average strength of concrete for all the projects studied is from 3,825 to 6,362 lbs. per sq. in. The average of the project averages is approximately 5,000 lbs. per sq. in.

5. Conditions on the projects studied have been so varied that a clear relation between amount of pavement wear and strength of concrete is not subject to definite conclusion at this time.

6. The amount and character of traffic and in some cases the character of aggregate used appear to be the most important factors affecting the wear of the pavement.

7. In general the 28-day strength of field cylinders is a good indication of the ultimate strength of concrete as shown by drill cores.

8. Design and maintenance of drainage features for removal of both surface and subsurface water are of paramount importance, and especially so in clay soils.

9. Further investigation will be required in order to determine the best method of subgrade treatment.

10. The mechanical analysis, moisture equivalent and lineal shrinkage tests have been fairly satisfactory for determining the qualities of soils. The value of the vertical capillarity test is questionable.

11. Factors tending to produce concrete whose absorption is high also tend to lower its compressive strength.

RECOMMENDATIONS

1. If the moisture content in clay soils is apt to be high, even for a short period, the subgrade should be treated.

2. A continuation of the pavement and subgrade studies in Colorado is believed to be justified. Intensive studies in certain localities should be made to determine the seasonal variation in moisture content of the subgrade soil. The field work is a vital part of these investigations and should be in the immediate charge of a man having a knowledge of geology as well as a thorough understanding of the engineering problems involved.

BIBLIOGRAPHY

Procedure for Testing Subgrade Soils, by Boyd, J. R., ''Public Roads,'' April, 1925, page 34.

Present Status of Subgrade Studies, by Rose, A. C., ''Public Roads,'' September, 1925, page 137.

Practical Field Tests for Subgrade Soils, by Rose, A. C., ''Public Roads,'' August, 1924, page 10.

Adaption of Atterberg Plasticity Tests for Subgrade Soils, by Wintermeyer, A. M., ''Public Roads,'' August, 1926, page 119.

Principles of Final Soil Classification, by Terzaghi, Charles, ''Public Roads,'' May, 1927, page 41.

Determination of Consistency of Soils, by Means of Penetration Tests, by Terzaghi, Charles, ''Public Roads,'' February, 1927, page 240.

Subgrade Studies of the U. S. Bureau of Public Roads, by Hogentogler, Mullis and Benkelman, ''Public Roads,'' March, 1927, page 1.

Progress in Subgrade Soil Investigations, by Eno, Frank H., ''Roads and Streets,'' February, 1927, page 82.

Principles of Soil Mechanics, (8 articles) by Terzaghi, Charles, Engineering-News Record, Vol. 95, July-December, 1925, pages 742, 796, 832, 874, 912, 987, 1026, 1064.

APPENDIX A

PREPARATION OF SOIL SAMPLES

From the sample of soil as received from the field, two samples of approximately 400 grams and 200 grams were taken. The 200 gram sample was weighed, dried at a temperature not exceeding 100° C, re-weighed and its original moisture content computed. This sample was then broken down, passed through a ¼-in. screen, and the fractions weighed. From the portion passing the ¼-in. screen, a sample for the mechanical analysis test was obtained by the method of quartering. The remainder was pulverized by means of a rubber covered roller which was moved with a combined rolling and sliding motion across a rubber covered plate. All the material retained on a 10-mesh sieve was discarded and samples taken for the moisture equivalent and vertical capillarity tests.

The 400-gram sample was dried, pulverized and all material retained on a 10-mesh sieve discarded. The material passing the 10-mesh sieve was used in the lineal shrinkage test.

APPENDIX B

MOISTURE EQUIVALENT TEST

The moisture equivalent of a soil is defined as the amount of moisture, expressed as a percentage of the dry weight of the sample, retained by soil when it is subjected to a centrifugal force equal to 1,000 times the force of gravity. The apparatus used in the test is shown in Figure 14, and the procedure for determining the moisture equivalent is as follows: (A practical field test for determining the approximate moisture equivalent percentage of soils is described in "Public Roads," Vol. 5, No. 6, August, 1924, p. 10.)

A 5-gram sample of the soil, prepared as described under "Preparation of Soil Samples," is placed in a Gooch crucible, the bottom of which has been previously covered with a piece of filter paper, and allowed to take up moisture until completely saturated. It is then placed in a damp closet over night to insure a uniform distribution of moisture throughout the soil mass, after which the crucible is placed in a Babcock cup, in the bottom of which is a rubber stopper, shown in Figure 14, with a hole through its center sufficiently large to hold the water thrown out by the centrifuge. Besides receiving the ejected water, the stopper also serves as a cushion. The Babcock

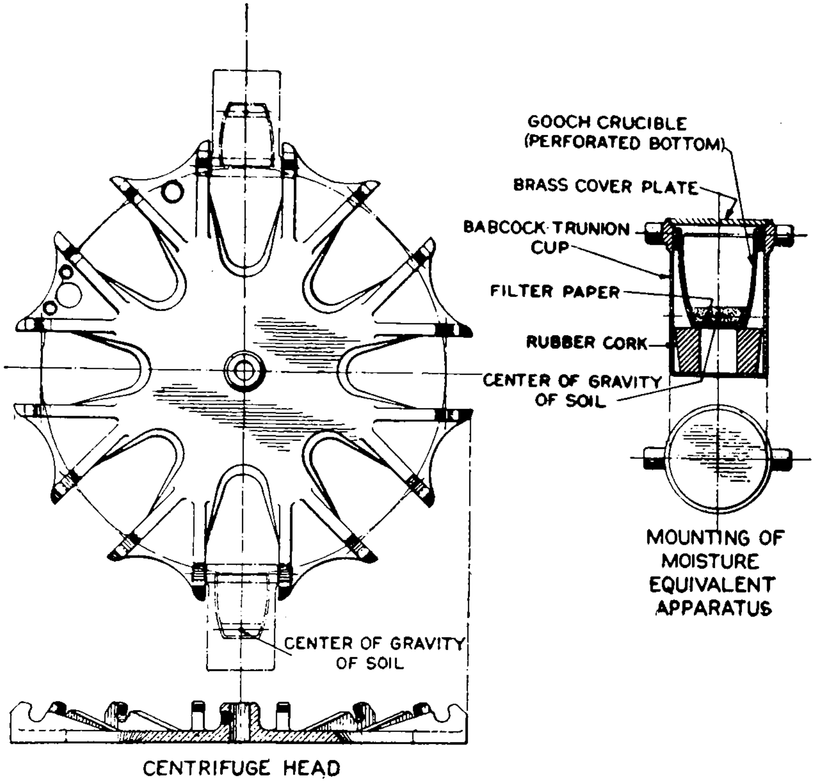

Figure 15.—Apparatus for determining the moisture equivalent of subgrade soils.

cup is provided with a brass cap to prevent evaporation. The sample is centrifuged for a period of one hour, at a speed which, for the diameter of head used, will exert a centrifugal force 1,000 times the force of gravity, upon the center of gravity of the soil sample. Immediately after centrifuging, the sample is weighed, dried in an oven to constant weight at a temperature not exceeding 100° C. (212° F.), and a second weight determined. The moisture equivalent of the soil is calculated from the following formula:

$$\text{Moisture equivalent} = \frac{(A\text{-}b) - (A^1\text{-}b^1)}{A^1 - (a + b^1)} \times 100$$

in which

A =weight of crucible and contents after centrifuging.
A^1=weight of crucible and contents after drying.
a =weight of crucible.
b =weight of filter paper wet.
b^1=weight of filter paper dry.

The test should always be made upon duplicate samples and these should be placed opposite to each other in the centrifuge, care being taken to accurately counterbalance them.

The variation between the two values obtained should not exceed 1 percent for values of the moisture equivalent up to 15 percent, and 2 percent for values above 15 percent.

APPENDIX C

CAPILLARY MOISTURE TEST [1]

The capillary moisture of a soil may be considered as the amount of moisture the soil is capable of taking up against the force of gravity. All subgrade soils have the ability to take up capillary moisture to some extent, and it is for the purpose of determining the relative amounts which can be taken up by subgrade soils of varying characteristics that the following test is used.

A sample of the soil, prepared as described under "Preparation of Soil Samples," is dried to constant weight in an oven at a temperature not exceeding 100° C. (212° F.), allowed to cool in a desiccator, and then poured loosely into a glass tube (inside diameter 25 millimeters), the bottom end of which has previously been covered with cheesecloth. The tube is jarred until the soil reaches a height of 10 centimeters and no further settlement takes place. The lower or covered end of the tube is then just immersed in water. When capillary moisture reaches the top of the soil column, the tube is weighed daily until it comes to constant weight. (A slight fluctuation in weight is to be expected due to barometric changes). The percentage of capillary moisture is then computed from the following formula:

$$\text{Percentage of capillary moisture} = \frac{(A\text{-}A^1)-(b\text{-}b^1)}{A^1-(a+b^1)} \times 100$$

in which

A=(weight of glass tube)+(wet soil)+(cheesecloth and rubber band wet).

A^1=(weight of glass tube) + (dry soil) + (cheesecloth and rubber band dry).

a =weight of glass tube.

b =weight of cheesecloth and rubber band wet.

b^1=weight of cheesecloth and rubber band dry.

([1] "Public Roads," August, 1925, page 36.)

APPENDIX D

FIELD METHOD FOR DETERMINING THE LINEAL SHRINKAGE PERCENTAGE OF SOILS

A 300 to 350-gram sample of soil was prepared as described in Appendix A, dried, and cooled in a desiccator. It was then wetted to vertical capillary moisture percentage and packed in a galvanized iron mold (1 inch × 1 inch × 12 inches). After a short time, the bar was removed from the mold and placed on a glass plate to dry. The bars were dried slowly and turned from time to time to prevent curling. A piece of paper on the glass plate aided in preventing cracking in the early stages of drying. When thoroughly dry, the bars were calipered and their lineal shrinkage determined. The shrinkage percentage as thus found was corrected for the material retained on the 10-mesh sieve.

APPENDIX E

MECHANICAL ANALYSIS OF SOILS

In making mechanical analysis (the apparatus employed is illustrated in Figures 4 and 5) of subgrade soils, four fractions were determined; namely, coarse material, sand, silt and clay. These terms are defined as follows:

Coarse material is all material retained above the 10-mesh sieve.

Sand is that material which passes a 10-mesh sieve, is retained on the 200-mesh sieve, and subsides through a height of 8 centimeters in ammoniated water (concentration 1:500) in 8 minutes.

Silt is that material which passes a 200-mesh sieve and subsides through a height of 8 centimeters in ammoniated water (concentration 1:500) in 8 minutes.

Clay is that material which passes a 200-mesh sieve, and which does not subside through a height of 8 centimeters in ammoniated water (concentration 1:500) in 8 minutes.

It was found by experience that a more accurate mechanical analysis was obtained if the analysis was made on material passing the ¼-inch screen instead of material passing the 10-mesh sieve. The reason for this is that without the action of water it was impossible to separate completely the fine material from that retained on the 10-mesh sieve. In view of this fact the mechanical analysis was made in the following manner:

From that part of the entire sample which passed the ¼-inch screen, as described in Appendix A, "Preparation of Soil Samples," a sample was selected, by the method of quartering, weighing approximately 50 grams.

This sample was placed in an oven and dried to constant weight at a temperature not exceeding 100° C. (212° F.). After cooling to room temperature in a desiccator, it was weighed and placed in a 1000 ml. beaker with approximately 500 ml. of clear tap water. The mixture was gradually brought to the boiling point during a period of one hour and then allowed to simmer for one hour, but actual boiling was avoided. After standing to cool, the supernatant liquid was siphoned off to a depth of 3 centimeters above the bottom of the beaker. Ammoniated water (concentration 1:500) was then added to the beaker to a depth of 11 centimeters and the material was thoroughly dispersed with a wing-tip policeman on a glass rod for a period of from 1 to 2 minutes, and then allowed to stand for 8 minutes. The supernatant liquid was then siphoned off to a depth of 8 centimeters from the surface of the liquid. Ammoniated water was again added to the beaker, and dispersion, sedimentation and siphoning repeated as before. This process was repeated until the supernatant liquid was clear after 8 minutes sedimentation. The "clay" had then been siphoned off and the "sand" and "silt" remained in the beaker. The material remaining in the beaker was then dried to constant weight at a temperature not exceeding 100° C., cooled and weighed, and a sieve analysis made, using sieves No. 10, 20, 60, 100 and 200. The time of shaking for sieve analysis was 15 minutes.

All fractions including "clay" and "silt" were expressed as percentages of the original dried sample including the material retained on the ¼-inch screen.