COMPACTION OF SOIL AND BASE MATERIAL ON THE BALTIMORE FRIENDSHIP INTERNATIONAL AIRPORT

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PRELIMINARY INVESTIGATIONS

The site, located in Anne Arundel County, Maryland, containing approximately 3,300 acres or 5 square miles, is bounded on the west by the Pennsylvania Railroad, on the east by the Hammonds Ferry Road, on the north by the Stony Run Road, and on the south by the Glen Burnie-Dorsey Road. The land is gently rolling, typical of the Coastal Plain of Maryland as it approaches the Piedmont Plateau. It is drained by three major streams: Cabin Branch, Sawmill Branch, and Stony Run. Ground elevation varies from about 80 to 195 ft. above sea level. Except for a few isolated areas west and north of the site, all land within 2 miles of the boundaries lies at an elevation lower than the general level of the airport runways.

The Coastal Plain of Maryland consists of plains, hills, and terraces largely of sand and gravel and is underlain by a succession of eastward dipping sheets of clays and sands lying on a sloping floor of older rocks. Where this floor of rock rises to the surface a few miles west of the site, the Piedmont Plateau begins. Most of the site is of Patapsco formation, which is comprised of some clay, many local sand bodies, and gravel deposits. The higher parts of the site are comprised of a terrace sand-gravel of the Sunderland formation. There are many lenses of a white silty clay. These lenses vary from a few square yards to many acres in extent and from an inch or less to 6 ft. in istration System Class A-3 (USED Types GP, GW, SP and SW and CAA Types E-1, E-2, E-3, and E-4). These sands and gravels extend to considerable depth. In some parts, mixtures of poorly graded sand, silt, and clay of both the friable and plastic types are found. These are mainly of PRA Class A-2 (USED Types SP and SF and CAA Types E-3, E-4, and E-5) and borderline Class A-2-4 (USED Type SF and CAA Types E-4 and E-5) soils.

The PRA Class A-2 soils occur largely in cut areas and provide an ample supply of material suitable for embankment construction. Much of the A-2 material was satisfactory for sub-base construction.

The clean sands and gravels classified as A-3 are ideal for pavement subbase or aggregate for sand-asphalt construction. They are generally rapid-draining and are not subject to frost heaving.

The white silty clay classified as PRA Class A-4 (USED Type CL and CAA Type E-6) is unstable when wet and is subject to frost heaving. The Liquid Limit is 30 to 32, the Plasticity Index, 10 to 12.

The soil information previously given, which generally indicates the extent of knowledge at the beginning of the rough grading operation, was obtained from existing geological and agricultural soil surveys and by analyzing samples of soils taken from over 400 borings at locations scattered over the area, supplemented by samples secured from existing railroad and highway cuts and by aerial photography. The following table shows the approximate sieve analyses of the various materials.

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TABLE 1

APPROXIMATE SIEVE ANALYSES OF SOILS

FRIENDSHIP INTERNATIONAL AIRPORT

Screen Size	Sand-Gravels*	Sands*	Silty-Clays*
1-1/2-in.	100	100	100
1-in.	95-100	100	100
1/2-in.	83-100	100	100
No. 4	68-90	97-100	100
No. 10	48-85	92-100	98-100
No. 20	26-78	84-100	96-100
No. 40	12-60	30-98	94-100
No. 60	4-36	12-60	85-100
No. 140	3-20	3-22	70-98
No. 200	2-18	2-18	65-97

*Percentage Passing.

During this period, Messrs O. J. Porter, Thomas A. Middlebrooks, B.K. Houk, and C. A. Hogentogler, Jr., advised the engineers on all problems relating to soil mechanics. From the information then available, tentative decisions were made as to pavement thickness and compaction methods.

ROUGH GRADING

The rough grading for the airport was begun on May 1, 1947. The project included 7,000,000 cu. yd. of excavation and was characterized by a very fast construction schedule, the contractor moving upward of 50,000 cu. yd. per day during the major part of the construction season. This part of the work brought the subgrade to 15 in. below finished grade.

Due to the unstable conditions in the construction industry and the prevailing excessive prices for excavation, it was decided to write the specifications in such a fashion that the bidder might know exactly how much compaction would be required and to provide for additional payment if the engineers should decide additional compaction was necessary. The specifications required embankments to be formed in layers of not more than 8 in. in loose depth and that they be compacted with heavy sheepsfoot tamper type rollers, having not less than 500 lb. per sq. in. pressure under the tamping feet. Four passes over each layer were to be performed at the contract unit price. The contract unit price did not include the addition of water, it being the opinion of the engineers that moisture adjustment would not be required. The economy of relieving the contractor of the gamble as to the amount of compaction required was reflected in his bid price of 25 cents per cu. yd. for excavation and 1-8/10 cents per cu. yd. for compaction. The previous trend of similar work had been in excess of 40 cents per cu. yd. for excavation and compaction.

At the beginning of the operation, the contractor doubted the efficacy of the heavy sheepsfoot rollers in compacting the sandy soils. Therefore, an experiment was carried out using a light sheepsfoot roller, a heavily loaded Tournapull, and a heavy sheepsfoot roller. It was found that the most satisfactory results could be obtained with the latter. Compacting in 8-in. layers, the light sheepsfoot roller gave average densities of 93 percent, the Tournapull averaged 86 percent, and the heavy sheepsfoot roller averaged 99 percent (all at 2-ft. depth).

The heavy sheepsfoot roller never "rode out", but left the surface in a rather loose condition. However, at a depth of 18 in. and more, the sand was found to be of fairly high density. Knowing that several feet of the top of all fills were to be compacted with a heavy rubber-tired roller, it was decided to make all density tests, during the rough grading, at a depth of 2 ft.; and very consistent results were obtained. The Modified Proctor Test was used, adjusted for percentage of gravel contained in the samples. The densities at 2-ft. depth ranged from 95 to 107 percent, with an average of 99 percent of laboratory maximum. Tests made at depths of 12 in. averaged 89 percent and at 18 in. averaged 93 percent. The efficiency of sheepsfoot rollers, in sands of the type encountered, was well demonstrated.

The fast construction schedule undoubtedly was of benefit in obtaining the high densities because the material from the cuts was not exposed long enough to dry out before being conveyed to the fills and compacted in place. At no time was it necessary to add moisture to obtain proper compaction, although the contractor sprinkled his haul loads frequently to keep down dust and to permit faster operation of earth-moving equipment. Typical material in the cut areas averaged 88 percent of laboratory maximum density, and weighed from 100 to 130 lb. per cu. ft. (dry). Actual measurements of shrinkage showed that 1 cu yd. of excavated material made only .77 cu. yd. of fill which provides a rough check on the relationship between densities in place and densities in the completed fills.

A great deal of exploration was done with earth augers to detect lenses of the white silty clay; and most of the large ones were located during the rough grading operation. Any of this material found within 5 ft. 3 in. of finished grade, that is, within 4 ft. of subgrade, and beneath the pavement and shoulder areas (150 ft. each side of center line on runways and 85 ft. on taxiways) was removed and replaced with selected sandy material. In many cases, additional cuts or borings were made through the remaining clay to the sandy soil below in order to reduce the size of the impervious lenses and decrease the later possibility of a perched water table. This silty material was used mainly in embankments beyond the pavement lines or it was wasted. If the clay was thoroughly dispersed through the sand, it was found to make satisfactory fill material; and it was used, in a few instances in areas to be paved but not within less than 6 ft of subgrade. Approximately 250,000 cu. yd. of this material were removed during the rough grading operation.

Approximately 165,000 cu. yd. of sand-gravel (A-3 material) were stockpiled near the northwest end of the northwest-southeast runway. Many smaller deposits were so intimately mingled with the white silty clay (A-4) that they could not practicably be separated therefrom. The stockpiled material later was used as aggregate for the two 3-1/2 in. sand-asphalt base courses of the flexible pavement.

PNEUMATIC COMPACTION ROLLER

During the preliminary investigation period, it had been decided that subsoil conditions were favorable to very heavy compaction and comparatively thin pavement. In order that confirmatory tests might be carried out to enable final design of pavement and to avoid delay to the paving operation, the Department of Aviation, in July, 1947, purchased a Porter heavy pneumatic compaction roller. The roller ready for use, but without ballast, weighs approximately 40 tons. One hundred sixty tons of cast iron ballast were furnished, giving a range in gross weight from 40 to 200 tons.

The roller consists of two articulated load boxes, each 20 ft. long, 7 ft. 4 in. wide, and 6 ft. high. Each box is supported by two wheels on a single axle. The wheels are fitted with 30 x 33 pneumatic tires. The two units are tied together by two bars on trunnion assemblies which allow the two units to oscillate. The tires are 60-ply nylon cords with an accredited manufacturer's capacity rating of 100,000 lb. each at an operating pressure of 120 to 150 psi. A towing tongue is provided and is equipped with standard hitch for attaching the roller to a crawler type tractor.

TEST PROGRAM

After delivery and acceptance of the pneumatic compaction roller (hereinafter referred to as the "supercompactor"), a program of tests was carried out for the purpose of deciding the number of passes most likely to be necessary for proper compaction during the subgrade and sub-base preparation phase immediately to precede paving.

The Corps of Engineers was interested in this test program and made available the services of several men who rendered invaluable assistance in making the necessary tests.

Unfortunately, the weather was very bad with rain, snow, and alternately freezing and thawing temperatures. These conditions were not conducive to accurate results Since it was planned to let a contract for compaction and paving early in the spring of 1948, there was no alternative but to proceed and to make allowances for the weather conditions

The test section was laid out with unrolled areas between strips. After fine grading, levels were taken at 10-ft. intervals longitudinally and transversely. In addition, a number of 6-in. square metal plates were buried at 6- and 12-in. depths along the center line of each strip, located accurately horizontally and vertically.

Four test strips were compacted with 4, 8, 16, and 28 coverages (two passes being required for one complete coverage).

After rolling, test pits were dug in rolled and unrolled areas; and triplicate field density and CBR tests were made at 1-ft. levels, to a maximum depth of 6 ft. These results varied widely due to weather and variegated soil types, but generally indicated marked improvement in strength

The metal plates furnished valuable information concerning movement of soils under compaction. As expected, the greatest movements were in the plates buried 6 in. deep. Movements were greatest in cut areas overlying clay lenses. Longitudinal movements ranged from .04 to 1.16 ft, lateral movements from 0.1 to 0.46 ft. and downward movements from .01 to .65 ft. Movements in fill areas were much smaller than those in cut areas. It was found that a satisfactory increase in density was obtained in about twelve coverages, after which the rate of increase declined.

Important information was obtained from the failures of the subgrade overlying small lenses of white silty clay with a perched water table. Rolling brought the water to the surface and severe rutting occurred. Where water was not encountered, no such failure was observed. Densities of sands under clay lenses were not improved as much as at equal depths where no lenses were present.

Movement of the soil, observed during the test program, was also noted during construction. It is interesting to note that rutting of the surface occurred where rolling was carried out across the boundary of a previously compacted section. This apparent failure was attributed to the higher density and consequent greater resistance to movement of the already compacted material. In these cases, when borings showed that no unsatisfactory soil was present, the surface was smoothed in order to facilitate operation of the supercompactor and rolling was continued. After the initial four passes, rutting became less severe and finally disappeared.

An attempt was made to correlate the data into exact rules regarding supercompaction; but for several reasons, in addition to the weather, such correlation was found impracticable. These reasons are: (1) in spite of the fact that the location selected for the test apparently was of uniform consistency, about half on cut and half on fill, it was found, under detailed examination, to contain almost as wide a range of soil as does the entire airport site (sand-gravels with as much as 35 percent gravel, sands of all types, and ever-present lenses of white silty clay); and (2) CBR tests made in the field could not be correlated with those made in the laboratory on identical soil, although the laboratory test results were very consistent within themselves.

The test program did, however, fulfill its major purpose, that of obtaining sufficient data for preparing the plans and specifications for subgrade and sub-base preparation and paving. It indicated that, in the absence of clay lenses, densities of 100 percent could be obtained by supercompaction to a depth of at least 3 ft.

SUBGRADE AND SUB-BASE PREPARATION

This work was begun on March 12, under Contract No. 7. Thé contractor was allowed to use the supercompactor previously purchased by the City and was required to maintain the equipment and carry adequate insurance but was charged no rental.

From the test program it had been estimated that fills would settle about 2 in. and cut areas from 4 to 6 in. under supercompaction Twelve complete coverages with the supercompactor and 8 passes with a heavy sheepsfoot roller were specified. The pavement, based on a 100,000-lb. desigh wheel loads, was determined to be 10 in. of asphalt-bound material and 5 in. of selected granular material, plus the additional thickness due to the variable amount of settlement to be experienced under supercompaction. This space also was filled with carefully selected granular material from the site; and all of the granular material was rolled with the supercompactor.

Here, again, major economies were achieved by specifying the amount of compaction and providing for payment for additional compaction, the contractor's price for subgrade preparation being only 3 cents per sq. yd.

The first step was to make four coverages on the subgrade with the supercompactor, first, to detect weak spots or as yet undiscovered lenses of white silty clay and, second, to accomplish the gross settlement before pipe and duct lines were installed and before sub-base material was placed. About 50,000 cu. yd. of white clay were removed during this phase of the operation. This clay was replaced with carefully selected granular material. Utilities were installed and the trench refill compacted by mechanical tampers and by tractors and sheepsfoot rollers.

The sub-base material was placed and disced to mix it with the subgrade material, then given eight passes with the very heavy sheepsfoot roller, followed by eight additional coverages with the supercompactor. No matter how much compactive effort was applied to trenches by other means, several inches of settlement occurred under the supercompaction. This settlement of trench refill, regardless of compaction method, led to the adoption of soil-cement as a refill material alongside certain structures which were of necessity built after the completion of rolling. Local sand, often that removed in excavation for the structures, was used with the addition of three bags per cu. yd. of Portland cement mixed in a concrete mixer. This type of refill was brought to the elevation of the bottom of the asphalt-bound base.

Where sands were of uniform grain size, it was found necessary to blend other material in order to tighten up the subgrade sufficiently to permit proper supercompaction. The only nonplastic fines available were in the very poor sandy topsoil salvaged from the site. Vegetable matter was almost nil and the admixture of this soil made it possible to obtain a dense, hard surface upon which to place the first course of paving. Effective results also were obtained by blending well graded sand-gravels into the subgrade. Unfortunately, the quantity available was limited. Most effective supercompaction was obtained when the field moisture content was approximately 2 percent below laboratory optimum moisture content.

The supercompaction furnished the most reliable control of subgrade construction, every square foot of which was tested under loads approximating those to be applied under operating conditions.

The sub-base was finished by light blading, sprinkling when necessary, and then rolling with a 10-wheel, rubber-tired roller weighing about 11 tons.

The first course of sand-asphalt (3-1/2 in.) followed closely behind this treatment, in order to obviate further sprinkling and rolling and to cover the sub-base as fast as possible to permit upper course paving while waiting for the subgrade to dry out after heavy rains.

The total cost of compaction, 31 cents per sq. yd., is about the equivalent of the cost of 1 sq. yd. of flexible pavement 1 in. thick.

TABLE 2

ESTIMATED COST OF COMPACTION

Heavy sheepsfoot compaction of fills, prorated over paved area	$0.09
Four coverages of supercompactor on subgrade	0.03
Eight coverages of heavy sheepsfoot roller on sub-base	0.0625
Eight coverages of supercompactor on sub-base	0.06
Cost of supercompactor (depreciated 50 percent)	0.06
Tests and miscellaneous expense	0.0075
TOTAL	$0.31