DEVELOPMENT OF TURF ON STABILIZED SOILS

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SYNOPSIS

In the development and construction of military airfields, the Corps of Engineers has been faced with the necessity of constructing stabilized shoulders for airfield pavements and providing suitable turf cover thereon. War time construction of this type in the Florida sands indicated that satisfactory stabilization was accomplished by addition of limerock and that a good turf could be established on the stabilized surface.

To aid in establishing specific design criteria for such construction, investigations have been undertaken to determine the relation of the type of base material, thickness of base, degree of compaction, and rate of fertilization to the production of turf on various stabilized soils and the relative effectiveness of the turfed area developed by the different treatments for supporting various wheel loads.

Turfed areas of high load bearing capacity were required during the war training period for the safe operation of military aircraft and military vehicles. Many natural soils encountered while providing these areas were relatively unstable. Although no design criteria were available upon which to base construction methods, the results of strengthening the soils were such that the Corps of Engineers recognized the possibilities of the procedure and initiated several investigational projects described in this paper which it is hoped will lead to definite design methods.

This report is not intended as a technical discussion of base design but rather as a summary of stabilized turf base construction and the subsequent investigation. It is presented for the purpose of focusing attention on the fact that the development of turf on stabilized bases without topsoil is practicable. It is believed that the information has practical application in any construction where turfed areas of high load bearing capacity are desired.

War Construction - The majority of the soil stabilization work accomplished during the war was for the purpose of strengthening sandy soils, especially in the coastal areas of the southeastern United States. These soils normally have the lowest bearing capacity during periods of low rainfall, which is also the period of greatest operational activity. Stabilization was employed principally to provide runway and taxiway shoulders and end zones of sufficient strength to support occasional aircraft traffic. It was used also in the development of turf landing areas for light and medium weight aircraft. Road shoulders were strengthened where weight and volume of traffic dictated.

Strengthening of the noncohesive soils was accomplished by the incorporation of an aggregate or binding material into the natural soil or by placing a layer of selected material on a compacted subgrade. Stabilizing materials which were field tested included limestone, shell, sand clay, and marl. Available sand clay was of poor gradation and contained insufficient clay. Marl softened under conditions of extreme moisture and shell lacked required gradation. As a consequence limerock was used as the stabilizing agent for the majority of this type of work. A general description of limerock stabilization as practiced in Florida is presented as typical of the procedure. Table No. 1 is a tabulation of data concerning the construction of the projects mentioned herein.

TABLE 1

LOCATION AND TABULATION OF DATA CONCERNING
STABILIZED AND TURFED AREAS CONSTRUCTED BY THE CORPS OF ENGINEERS

Location	Topsoil		Base		Subgrade	Grass
	Material	Depth	Material	Depth		
Florida	None	-	Limerock & Sand	3" 3"	Medium to Fine Sand	Bermuda
MacDill Fld. Fla.	None	-	Sand Clay	8"	Medium to Fine Sand	Bermuda
MacDill Fld. Fla.	None	-	Limerock & Sand	6"	Medium to Fine Sand	Bermuda
Maxwell Fld. Ala.	None	-	Cohesion- less Sand Gravel	6" 10" 14"	Plastic Clay	Bermuda
Maxwell Fld. Ala.	None	-	Low Plastic Clay G'vl	6" 10" 14"	Plastic Clay	Bermuda
Nahant, Mass.	Loam & Pea Gravel	6"	Pitrun Pea Gravel	18"	Impervious Bitumen	Red Fescue
Nahant, Mass.	Loam & Pea Gravel	6"	3/8" Cr. Rock	18"	Impervious Bitumen	Red Fescue
Lafayette, Ind.	-	-	Sand Clay Gravel Limestone Traprock	12" 12" 12" 12"	Plastic " " "	Typical Cool Climate Grasses

Florida soils are generally noncalcareous sands and clays, graded from medium to fine and of uniform grain size and relatively low bearing value when in an unconfined state. Subgrade formations consist of limerock, oolite rock, and marine deposits of sands and clays. Outcroppings of limerock in central Florida and of oolite rock in the Miami area are not uncommon. Along the west coast and inland from Tampa south there is usually a stratum of hardpan several feet below the surface, causing a high water table. Where deep sands occur the water table is generally low.

Stabilization and grassing procedure were as follows:

a. Type and amount of stabilizing material to produce the desired results were determined by laboratory test of the soil to be stabilized.

b. Rocks or boulders within twelve inches of the surface and unstable material were removed and replaced with selected material.

c. The required amount of stabilizing material was spread uniformly over the soil to be strengthened and incorporated to a uniform depth of six inches.

d. Sufficient water was added to develop maximum density.

e. The surface was then brought to grade and the grass planted.

f. Area was compacted with rubber-tired and smooth rollers until desired density was attained.

Bermuda grass was used for practically all planting on limerock stabilization. Fertilizer was applied during incorporation of the limerock. Bermuda grass sprigs were planted in rows prior to compaction. During the early part of the program Bermuda grass seed was planted after the initial compaction was accomplished. Later it was determined that seed could be successfully planted prior to any compaction provided rubber-tired or smooth rollers were used. If a companion crop was used it was seeded prior to compaction.

Little difficulty was encountered in establishing Bermuda grass turf on stabilized soils. Natural low fertility of the native soil, aggravated by the addition of large amounts of infertile aggregates, made the use of heavy applications of fertilizer necessary. During the early part of the planting program the most readily available grade of nitrogen bearing fertilizer was used. Grades included 4-8- 6-2-0, 6-8-4, 8-6-4, and 10-6-4 containing as high as 40 percent organic nitrogen. Fertilizer for later plantings was generally standardized at 6-8-4 and 8-6-4 containing from 10 to 20 percent organic nitrogen. Rate of application was adjusted to apply from 40 to 60 pounds of nitrogen per acre per application. Although tests conducted during 1942-43 indicated that inorganic nitrogen on Bermuda grass gave equal or better results than the more expensive organic nitrogen, the continued use of a small percentage of organic material was required as a conditioner of the green fertilizer materials. Maintenance fertilization was done primarily with inorganic nitrogen in the form of ammonium nitrate or nitrate of soda. Sixty to 100 pounds of nitrogen per acre per year in two applications was common practice.

Investigations which indicated the desirability of inorganic nitrogen on Bermuda grass on sandy soils also indicated that repeat applications of phosphate or potash gave no appreciable response, nor could immediate effects of the minor elements be detected.

As previously noted, planting consisted of sprigging and seeding Bermuda grass. Most sprigging was accomplished with planting machines which provided for the application of water into the row and immediate coverage of plant material with soil. Overseeding with the Bermuda grass was a safety factor to assure a successful planting. Whether preponderance of plants came from seed or spriggs depended primarily on weather conditions.

Stabilized areas resulting from the above described treatment were adequate for supporting all aircraft up to and including the B-29 having a gross load of approximately 135,000 pounds. Results of the evaluation of one typical airfield after establishment of turf are indicated in Table 2.

TABLE 2

RESULTS OF EVALUATION OF A TYPICAL FLORIDA AIRFIELD
AFTER THE ESTABLISHMENT OF BERMUDA GRASS ON LIMEROCK STABILIZATION

Test No.	% Moisture	Density	CBR	Stabilized Depth in Inches
1.	4.0	110.0	48.3	6.5
2.	5.7	109.0	61.7	6.0
3.	6.0	112.7	55.0	5.5
4.	4.3	110.5	60.0	5.5
5.	5.3	109.2	50.9	5.5
6.	3.5	116.3	63.3	6.0
7.	6.1	116.3	93.3	5.5
8.	3.7	111.5	76.7	5.0
9.	3.4	114.7	38.3	6.0
10.	5.5	109.0	70.0	6.0
11.	5.4	109.9	35.8	7.0
12.	3.0	112.8	53.3	6.0
13.	3.9	112.0	60.8	5.0
Average	4.6	111.9	59.0	5.8

Other typical test data are presented in Figures 1 thru 6. Figure 7 illustrates photographically the ability of limerock stabilized soils to withstand the repeated impact of landing aircraft. The tire marks in upper photograph are from aircraft which have landed short of the runway. The two lower photographs show tire marks of B-29 aircraft which landed on the shoulder and rolled onto the pavement without damage to the aircraft.

Investigations - In 1945 two sections were constructed to secure supplemental data for the purpose of developing design criteria for the construction of stabilized turf areas. Specific objectives were to determine the relation of type of base material, thickness of base, degree of compaction, and rate of fertilization to the production of turf on stabilized soils and the relative effectiveness of the turfed area developed by the different treatments for supporting various wheel loads.

Turf Shoulder, MacDill Field, Florida - A section incorporating limerock and sand clay bases was constructed at MacDill Field, Florida, on a ball bearing sand subgrade. Construction was similar to that which would be employed in actual development of a traffic area. All vegetation was removed. Unstable subgrade material was replaced with a selected subgrade sand. Limerock and sand were mixed in equal portions to provide a six-inch compacted base. The sand clay base was placed in an eight-inch layer in an excavation which would bring the two bases to the same finished surface elevation. Fertilizer (6-8-4) was applied at rates of 500, 1,000, and 1,500 pounds per acre in six longitudinal lanes. The entire area was sprigged to Bermuda grass in 26-inch rows and overseeded to Bermuda grass. Each base was divided into three transverse lanes to receive light, medium, and heavy compaction. The plasticity index of the blended sand clay, shown in Table 3, indicates that the material will be unstable under conditions of high moisture. This is confirmed by the plastic flow which occurred in this base under traffic. Mechanical analyses of subgrade and base materials are shown in Figures 8 and 9.

MODIFIED PROCTOR CURVES

BLENDS OF TYPICAL DUNNELLON SAND & OCALA LIMEROCK

LEGEND

1	80% SAND /	20% OCALA	108.0 LBS/FT³	AT 11.9%	MOISTURE
2	70 " "	30 " "	109.8 "	" 11.5 "	"
3	60 " "	40 " "	110.6 "	" 11.7 "	"
4	50 " "	50 " "	114.8 "	" 10.4 "	"
5	40 " "	60 " "	118.4 "	" 9.9 "	"
6	30 " "	70 " "	118.8 "	" 10.7 "	"

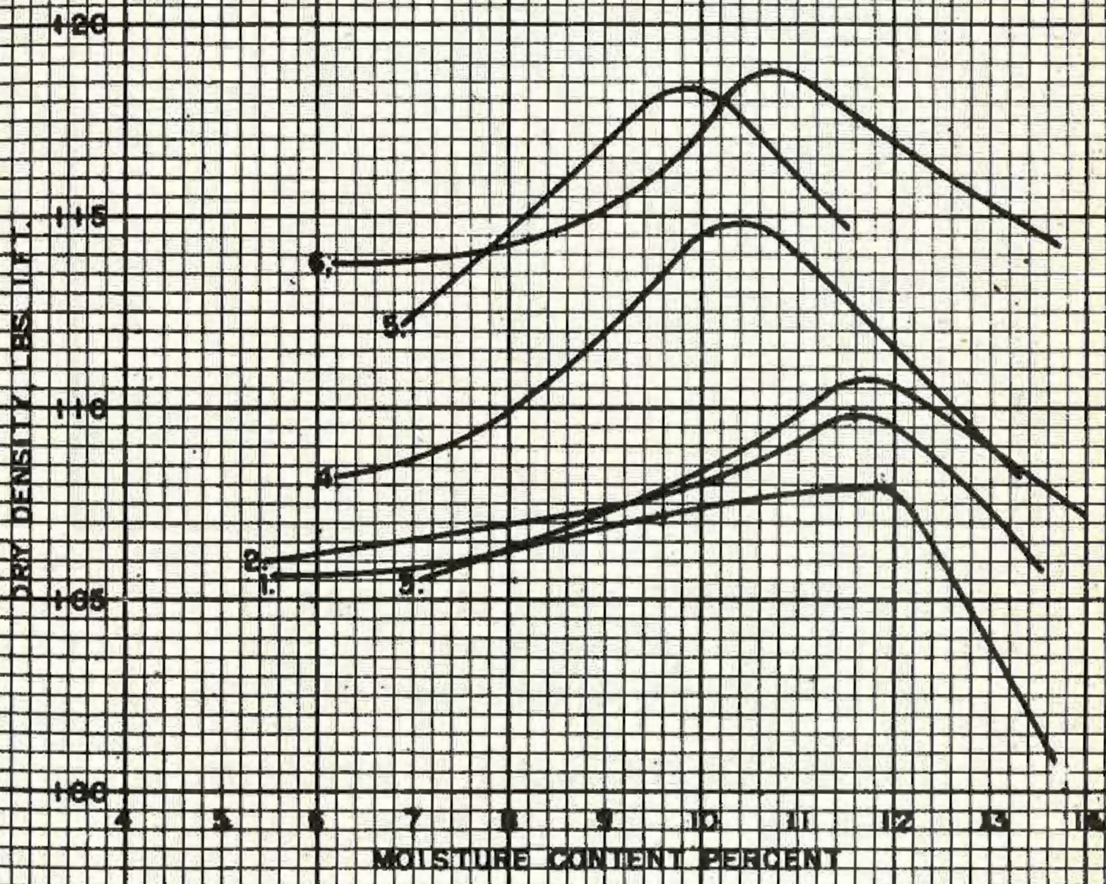
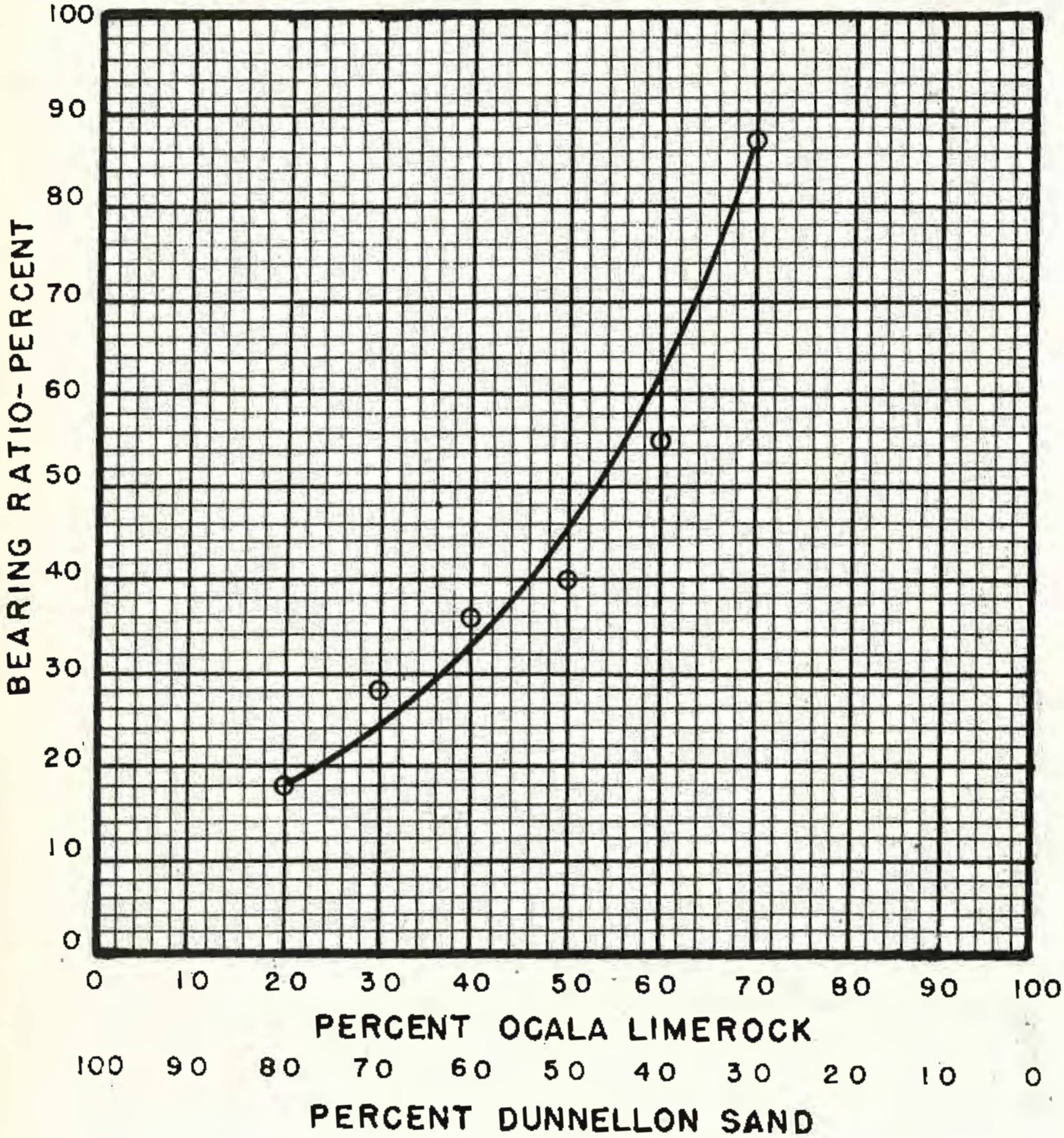


FIGURE - I.

BLENDS OF TYPICAL DUNNELLON SAND AND OCALA LIMEROCK.

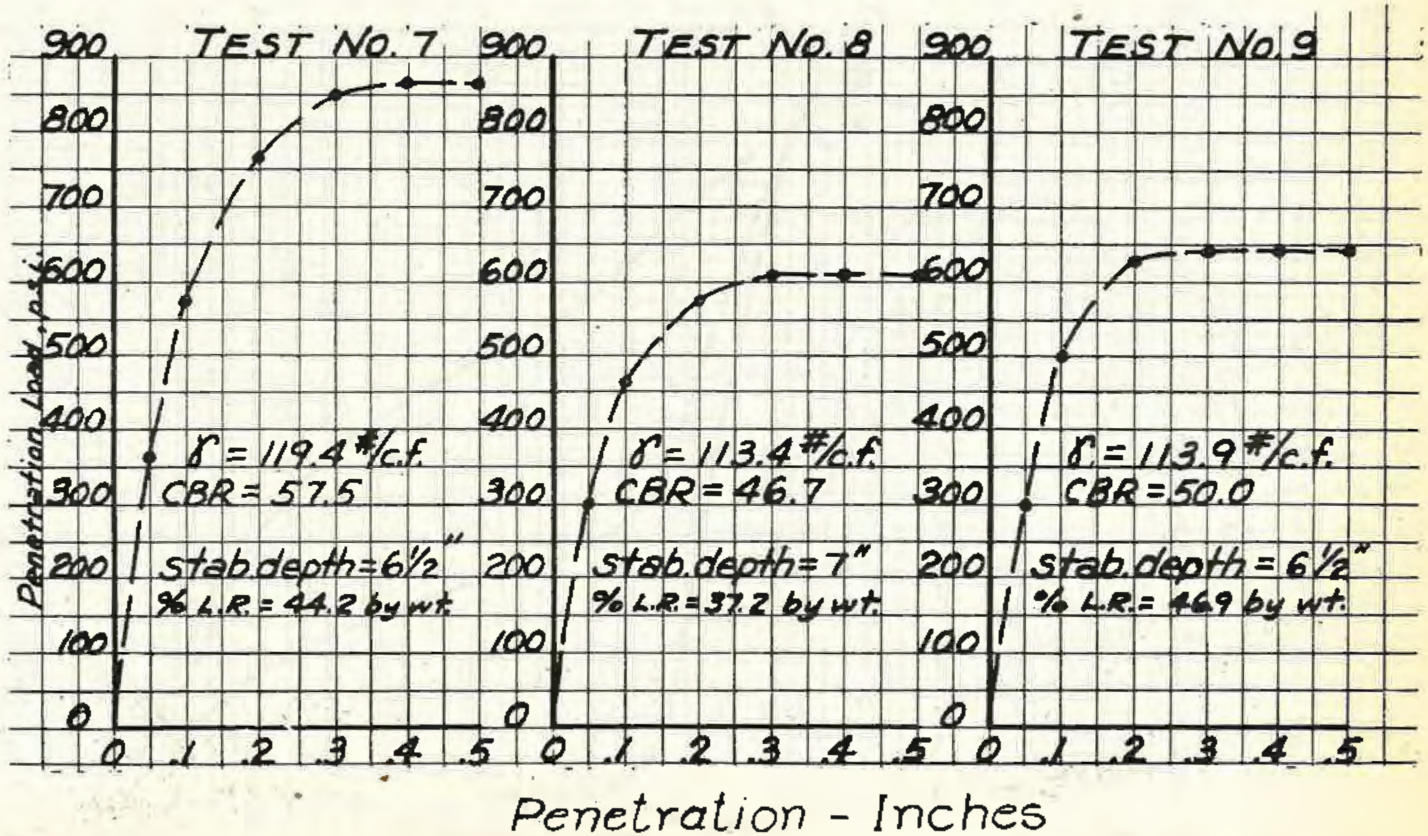


RELATION OF PERCENT STABILIZING MATERIAL TO CAL. BEARING RATIO

FIGURE-2

FIELD C.B.R. TESTS ALLOVER STABILIZATION

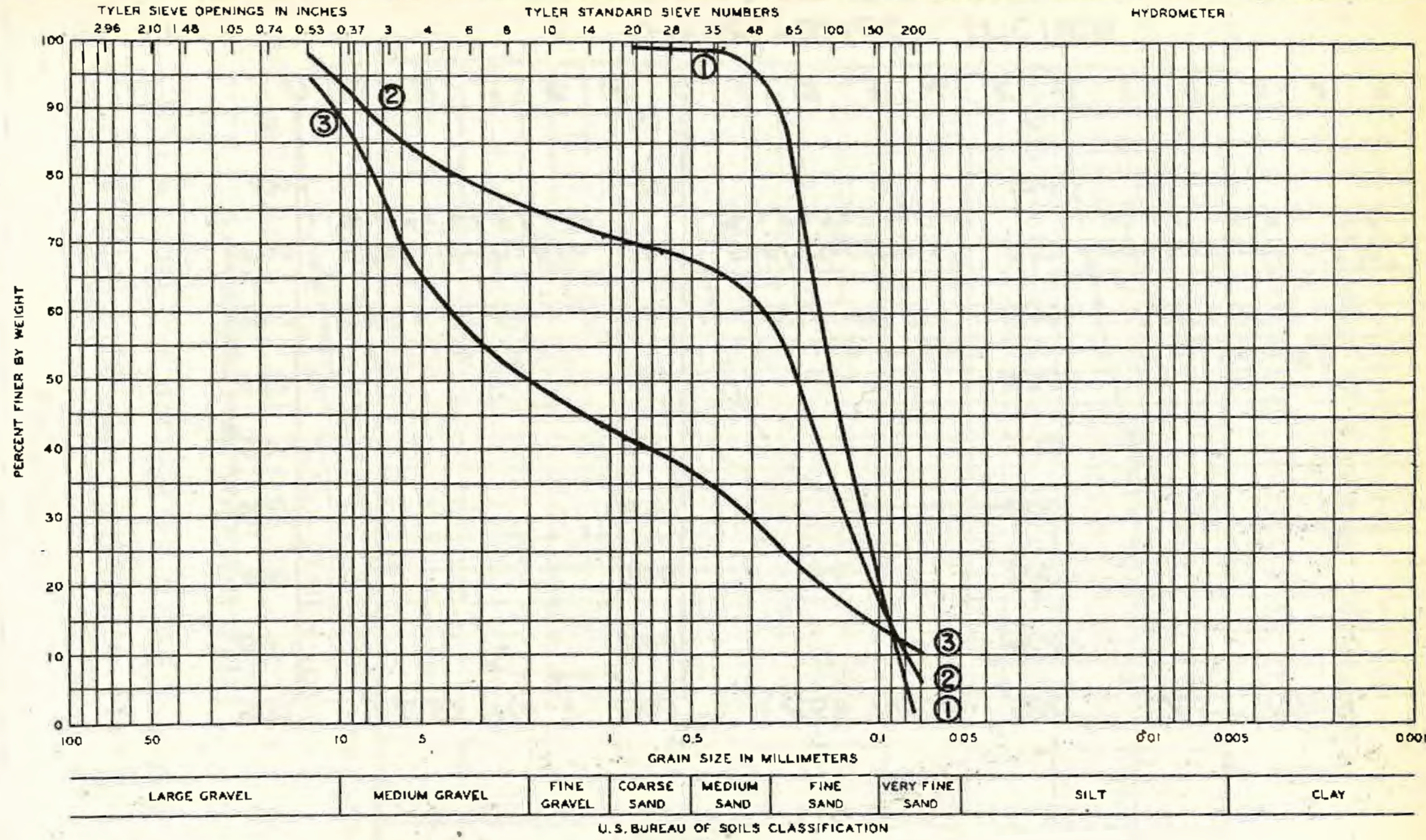
BLENDS OF TYPICAL DUNNELLON SAND & OCALA LIMEROCK



FIGURE—3

WAR DEPARTMENT

CORPS OF ENGINEERS, U S ARMY



SAMPLE NO. ① TYPICAL DUNNELLON SAND

SAMPLE NO. ② 50% DUNNELLON SAND # 50% OCALA LIMEROCK

SAMPLE NO ③ OCALA LIMEROCK

FIGURE – 4

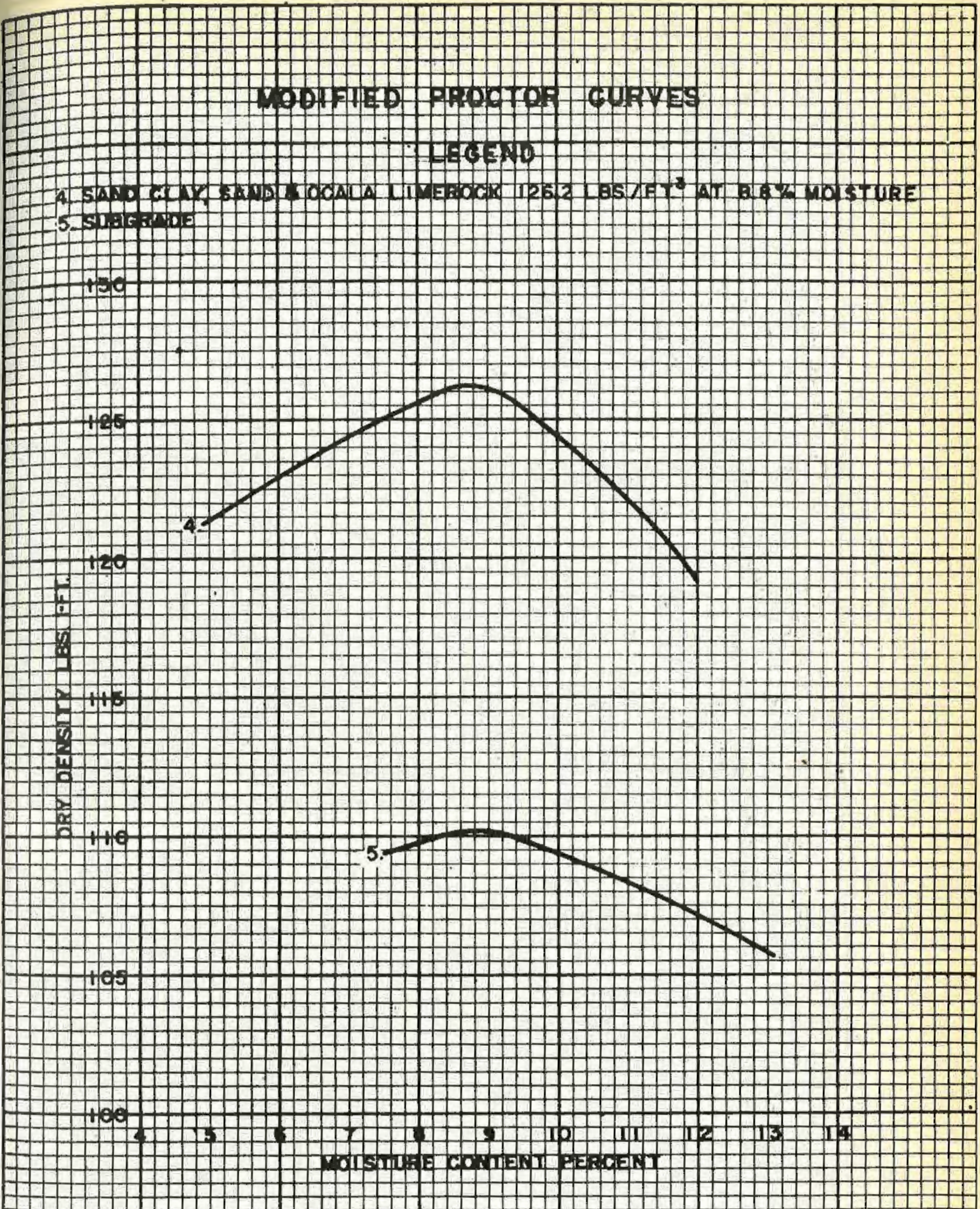
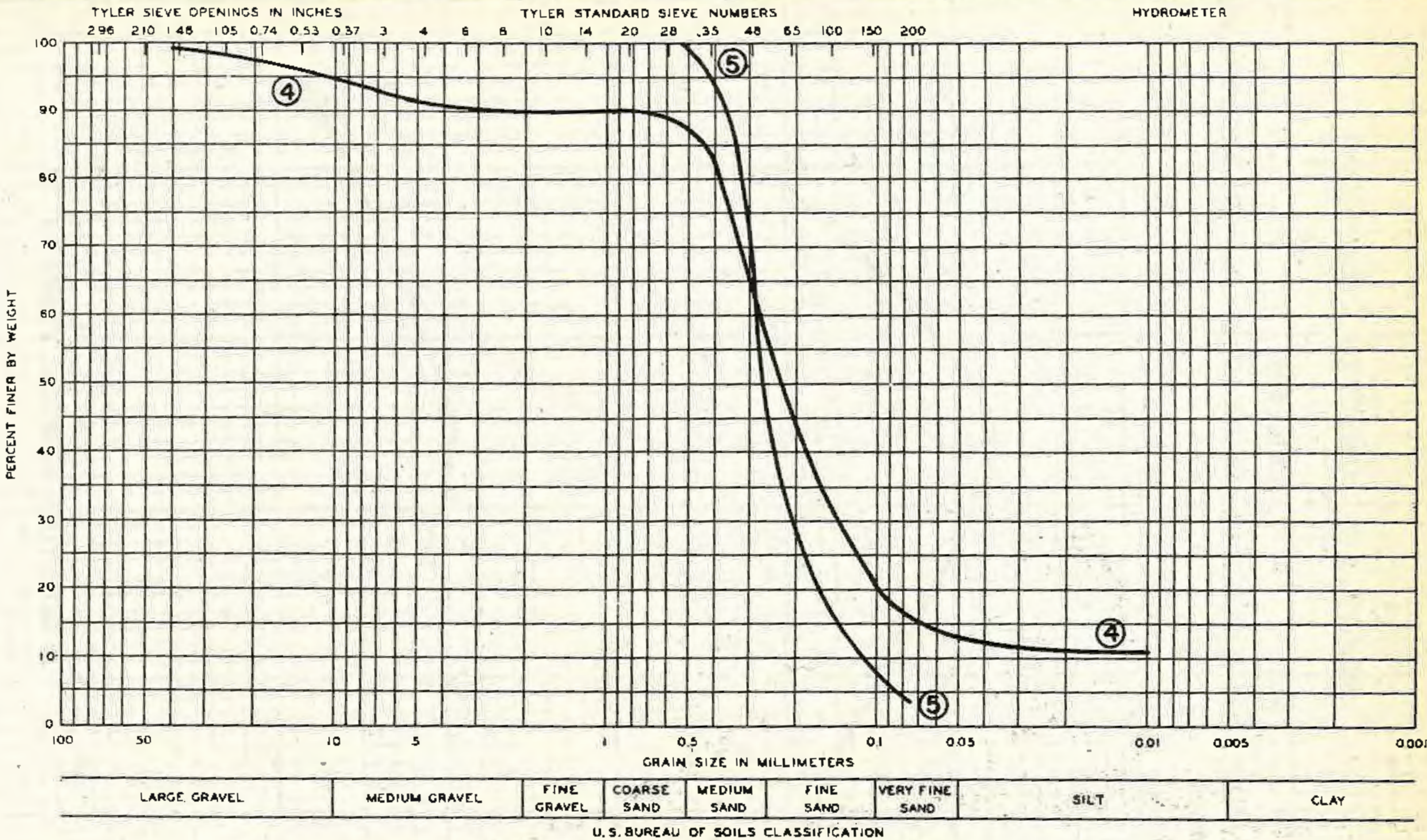

MODIFIED PROCTOR CURVES
LEGEND
4. SAND CLAY, SAND & OCALA LIMEROCK 126.2 LBS/FT³ AT 8.8% MOISTURE
5. SUBGRADE
130
125
120
115
110
105
100
DRY DENSITY LBS FT.
4
5
4
5
6
7
8
9
10
11
12
13
14
MOISTURE CONTENT PERCENT

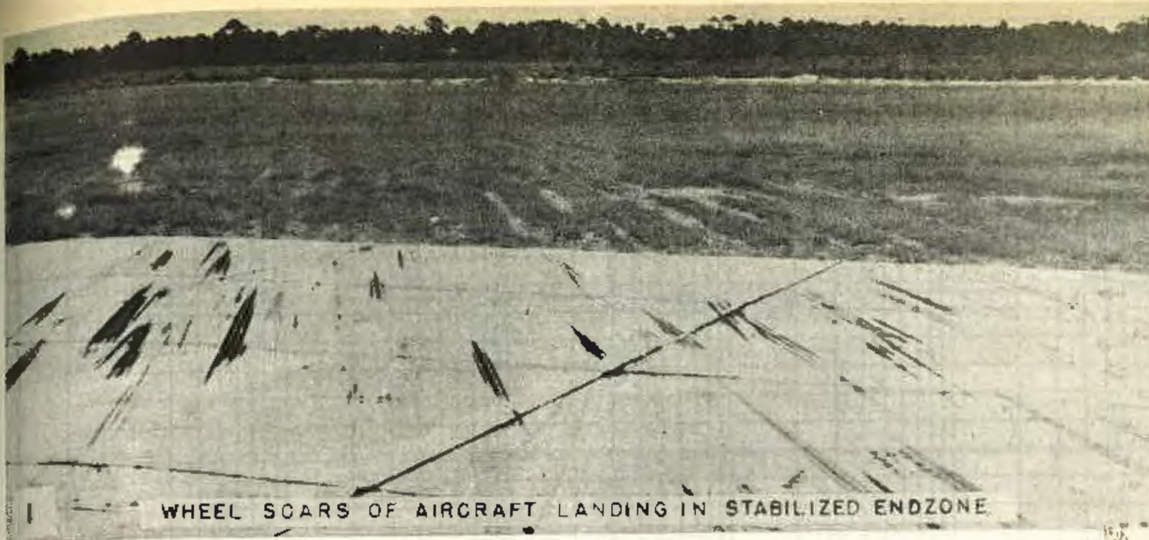
FIGURE-5

WAR DEPARTMENT CORPS OF ENGINEERS, U.S. ARMY

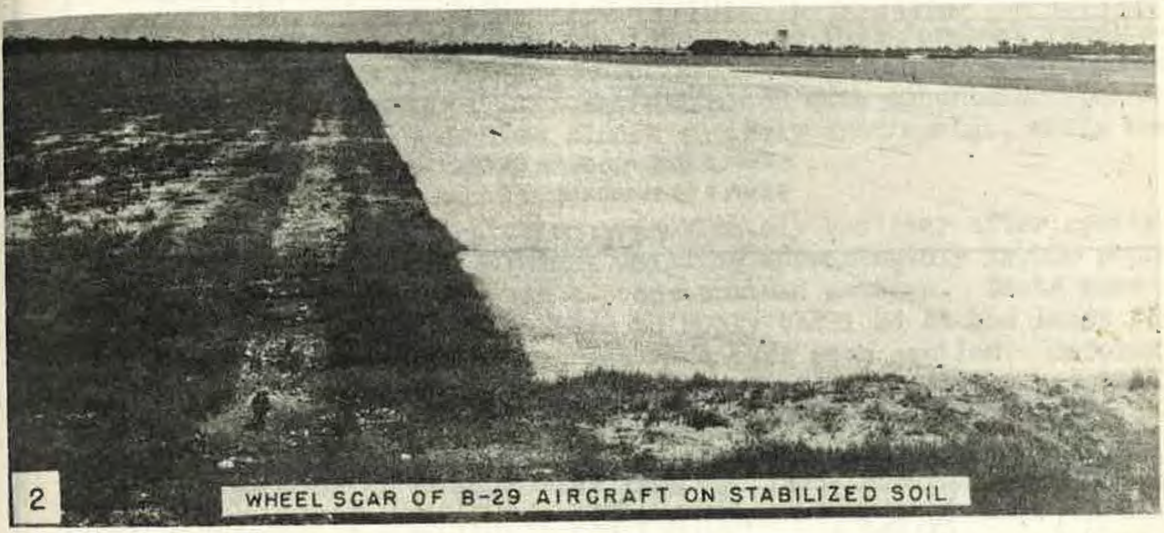


SAMPLE NO ④ LIMEROCK SAND CLAY & SAND MIXTURE
SAMPLE NO ⑤ SUBSOIL UNDER STABILIZED AREA

FIGURE-6



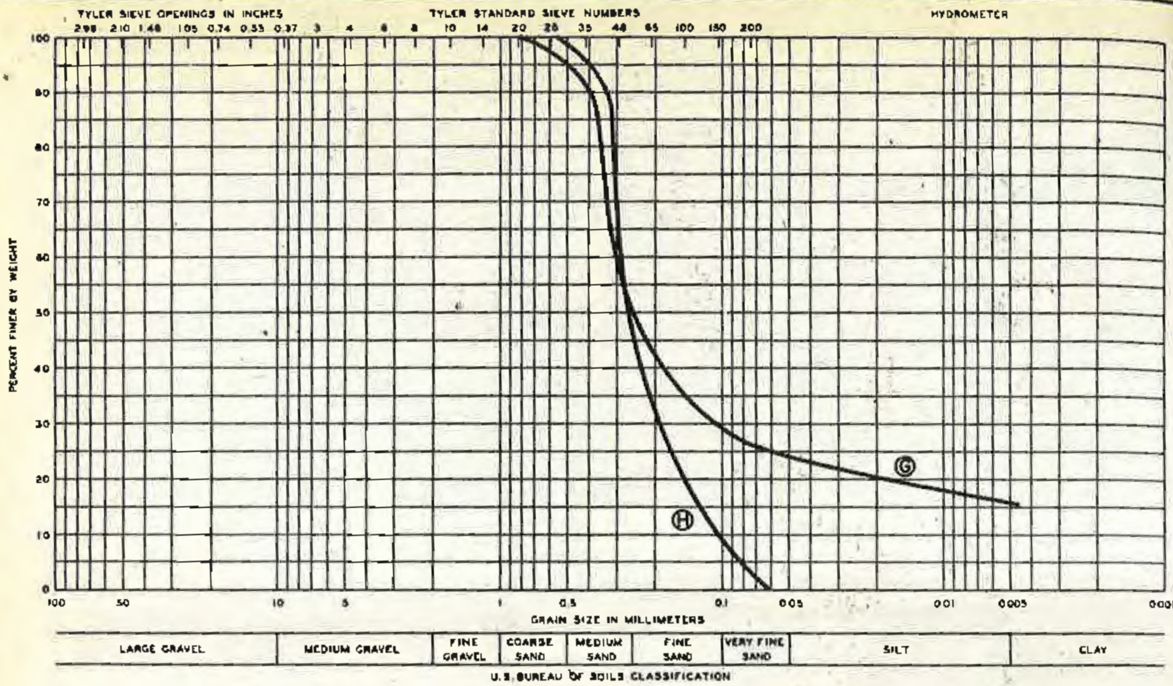
1 WHEEL SCARS OF AIRCRAFT LANDING IN STABILIZED ENDZONE



2 WHEEL SCAR OF B-29 AIRCRAFT ON STABILIZED SOIL

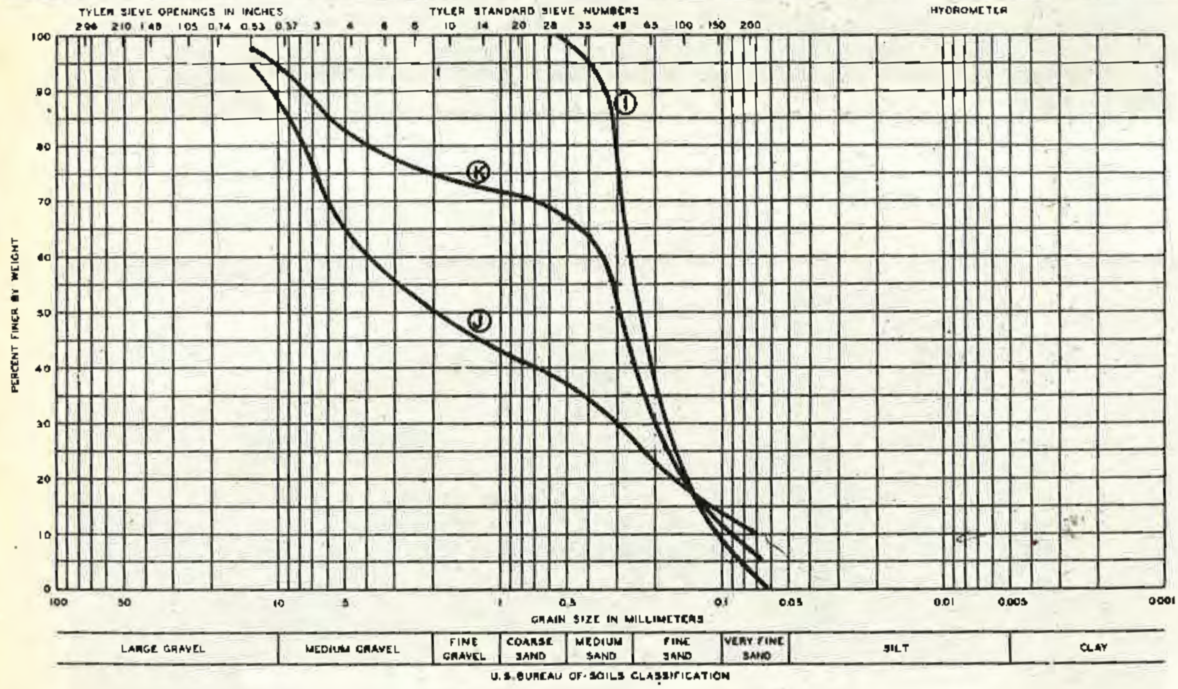
3 WHEEL SCAR OF B-29 AIRCRAFT ON STABILIZED SOIL

FIGURE-7



SAMPLE Ⓖ SAND CLAY BASE
SAMPLE Ⓗ SUBGRADE

FIGURE – 8



SAMPLE Ⓘ SUBGRADE
SAMPLE Ⓙ OCALA LIMEROCK
SAMPLE Ⓚ BLEND 50% Ⓘ 50% Ⓙ

FIGURE – 9

TABLE 3

PHYSICAL PROPERTIES OF PIT-RUN SAND CLAY BASE MATERIAL AND OF THE SAME MATERIAL AFTER MIXING IN PLACE

Sample No.	Atterberg Limits		
	LL.	P.L.	P.I.
	(Pit-Run Samples)		
1.	33.4	18.9	14.5
2.	26.9	18.4	8.5
3.	32.0	18.4	13.6
4.	21.7	-	5.1
	(After Mixing)		
sc1.	32.2	17.6	14.6
sc2.	30.7	17.4	13.3
sc3.	30.0	16.0	13.2

Construction was completed too late in the fall for best results from seed. For this reason the section was reseeded in the spring to furnish a comparison of the effectiveness of seeding on the two different base materials. The final turf cover on the sand clay was derived almost entirely from sprigs, while both sprigs and seed were effective on the limerock base.

Sections were traffic tested approximately one year after construction. Load was applied with a B-17 aircraft weighing approximately 54,000 pounds which was taxiied under its own power in a predetermined pattern. Tests were made following a prolonged dry period in order to apply the load at the least favorable period. A maximum of eleven passes was made over each section. Deformation measurements were made from a bridge resting on preset grade stakes paralleling the track. Maximum deformation of the limerock was approximately 0.1 ft. and of the sand clay was approximately 0.22 ft. Deformation is shown graphically in Figure 10. Maximum deformation of sand clay base was associated with greater moisture content. The range of moisture contents at time of test is shown in Table 4.

Turf density and effect of wheel load are shown in top photographs of Figure 12. The lower photographs in same Figure show a cross section of the two bases. Note slight subgrade compaction compared with considerable lateral displacement in the sand clay base.

TABLE 4

MOISTURE CONTENT OF TEST SECTION, MACDILL FIELD, FLORIDA, AT TIME OF TRAFFIC TEST

Compaction	Lane No.	Percent moisture by weight		
		sand clay	limerock	subgrade
Medium	F	13.2		13.6
Medium	D	13.6		12.4
Heavy	F	11.5		10.7
Heavy	D	13.6		12.8
Heavy	B	14.5		13.2
Medium	B	15.4		12.4
Medium	D		11.1	13.2
Medium	F		9.5	4.5
Medium	B		9.9	11.5

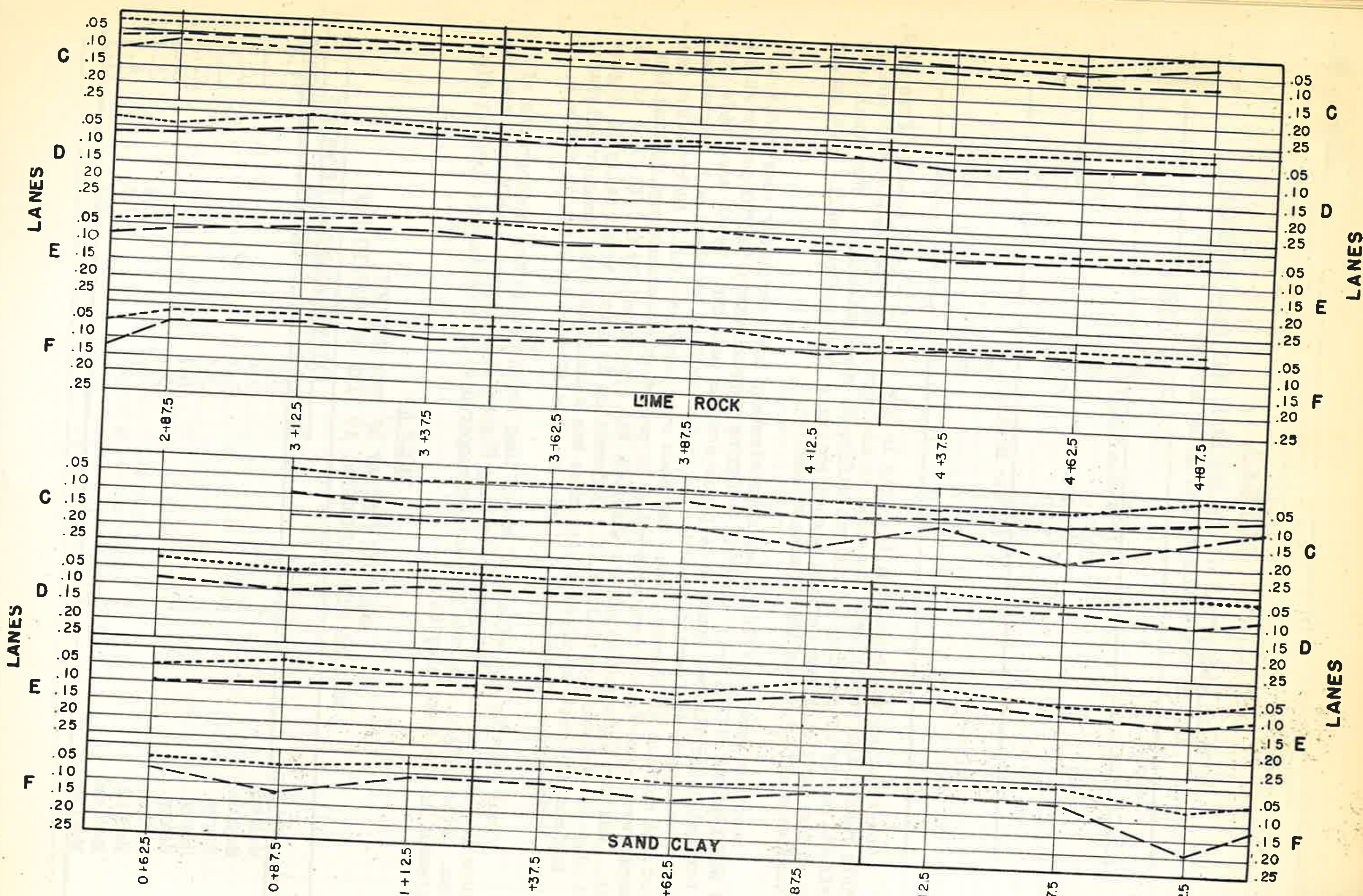
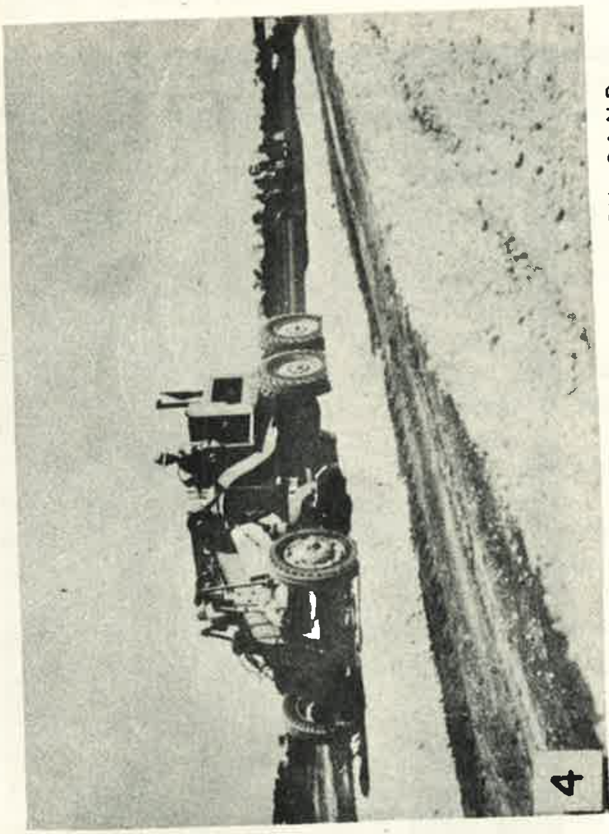
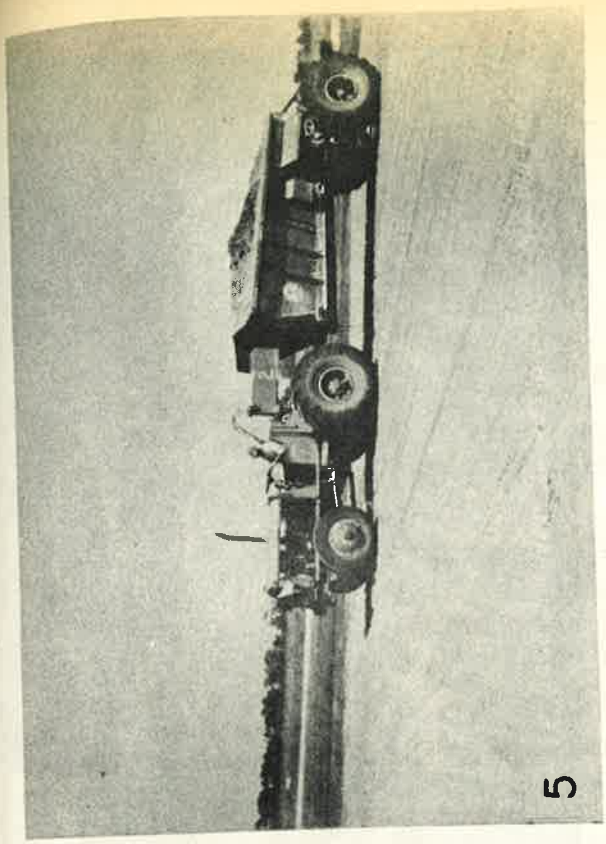


FIGURE — 10 DEFORMATION OF BASE CAUSED BY 26,625 POUND WHEEL LOAD

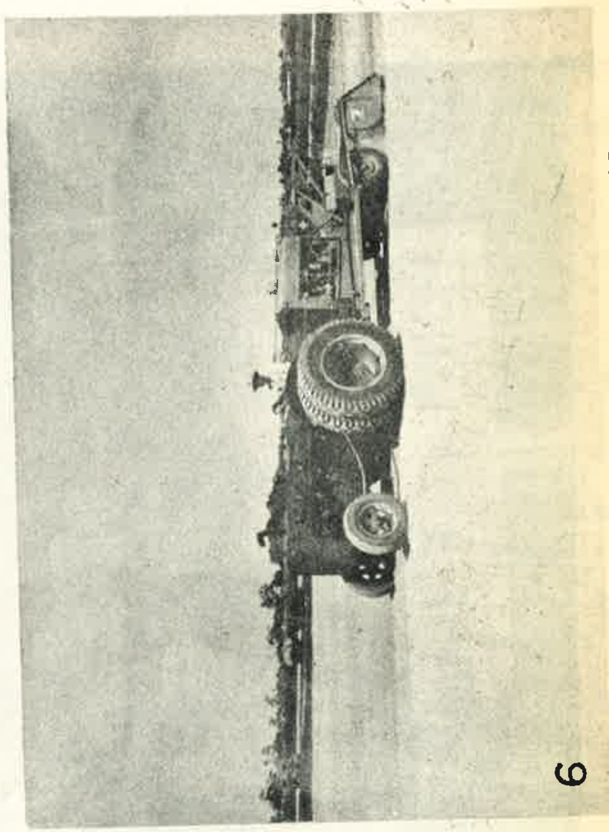
LEGEND - 1 PASS ---------
6 PASSES — — —
11 PASSES —·—·—



4 LIMEROCK PRIOR TO BLENDING WITH SAND



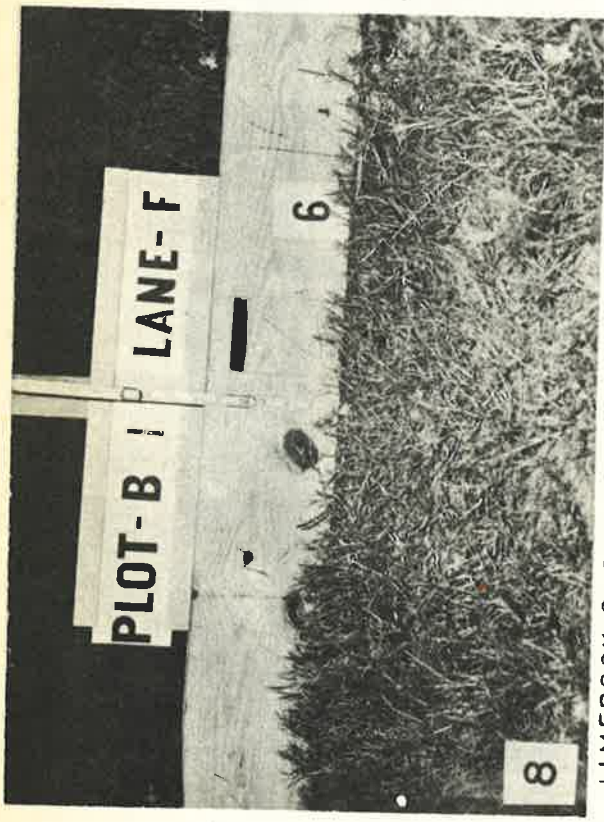
5 COMPACTING BASE AFTER PLANTING GRASS



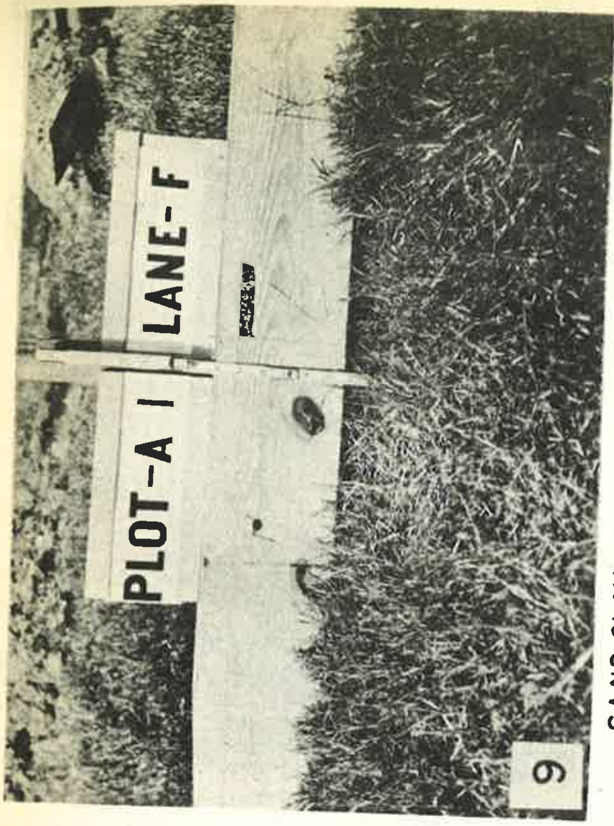
6 BLENDING LIMEROCK & SAND

7 BERMUDA GRASS FROM SPRIGS IN SAND-CLAY

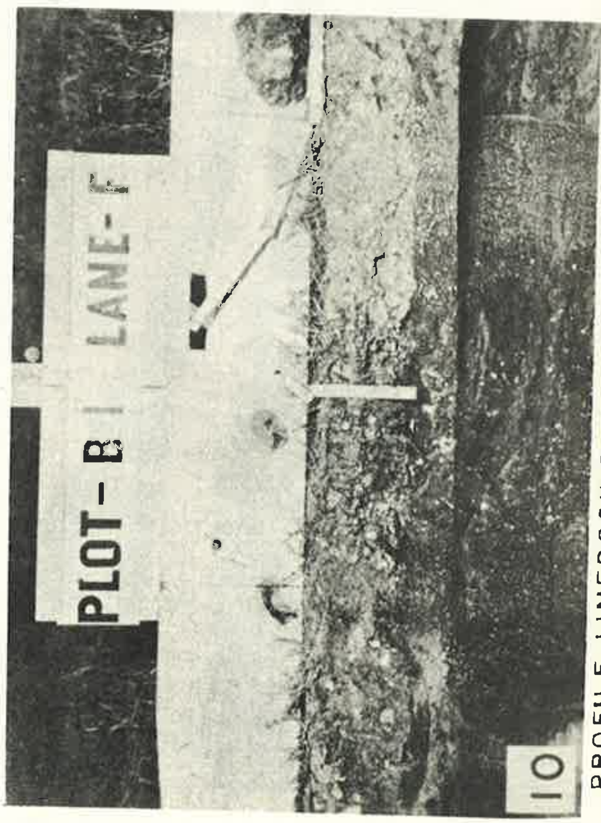
FIGURE-11



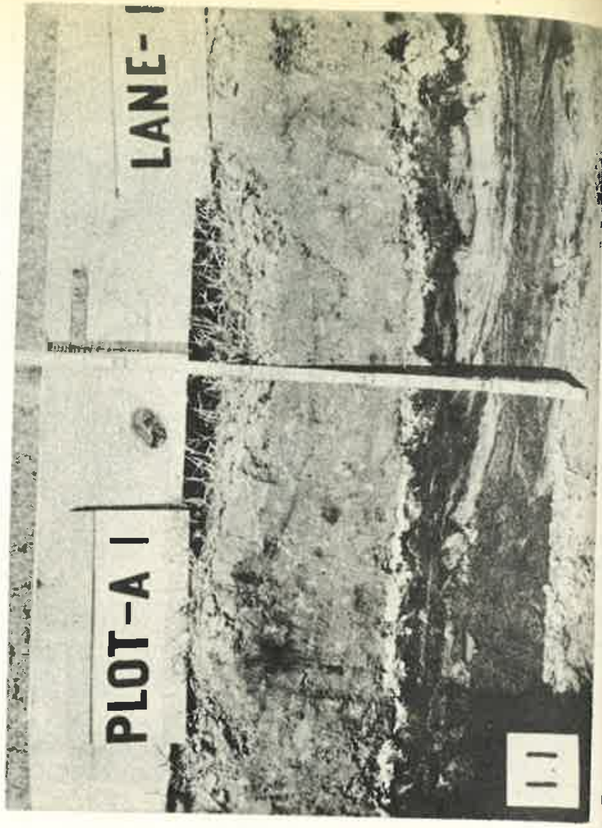
LIMEROCK & SAND BASE-6 LOAD APPLICATIONS



SAND-CLAY BASE- 6 LOAD APPLICATIONS



PROFILE-LIMEROCK & SAND BASE-6 LOADS 26,625 LBS.



PROFILE- SAND-CLAY BASE- 6 LOADS.

FIGURE-12

Turf Shoulder, Maxwell Field, Alabama - A runway shoulder section was constructed at Maxwell Field, Alabama, for a study of the development of stabilized turfed bases on a plastic subgrade. Base materials consisted of a noncohesive sand gravel and a low plastic clay gravel. Base materials were taken from a pit at the site and blended to secure the desired gradations. The construction and testing of the section were similar to that at MacDill Field, Florida.

Base materials were placed in parallel lanes separated by a thirty-foot wide work area. Each lane was divided transversely into three sections and the base constructed to depths of six, ten, and fourteen inches. The subgrade was excavated sufficiently to bring the finished surface to the same general surface elevation.

Each test section was sprigged to Bermuda grass and the entire test area, including work lane, was seeded to Bermuda grass at the rate of ten pounds per acre. Fertilizer (6-8-4) was applied in longitudinal lanes to each base material at the rates of 500, 1,000, and 1,500 pounds per acre. No fertilizer was applied to the work lane.

Each base thickness received three degrees of compaction at right angles to the fertilizer lanes. Construction operations are illustrated in Figure 13. Physical properties of the subgrade, base materials, and the final blends are given in Table 5. Particle size distribution for the final blends are shown in Figures 14 and 15.

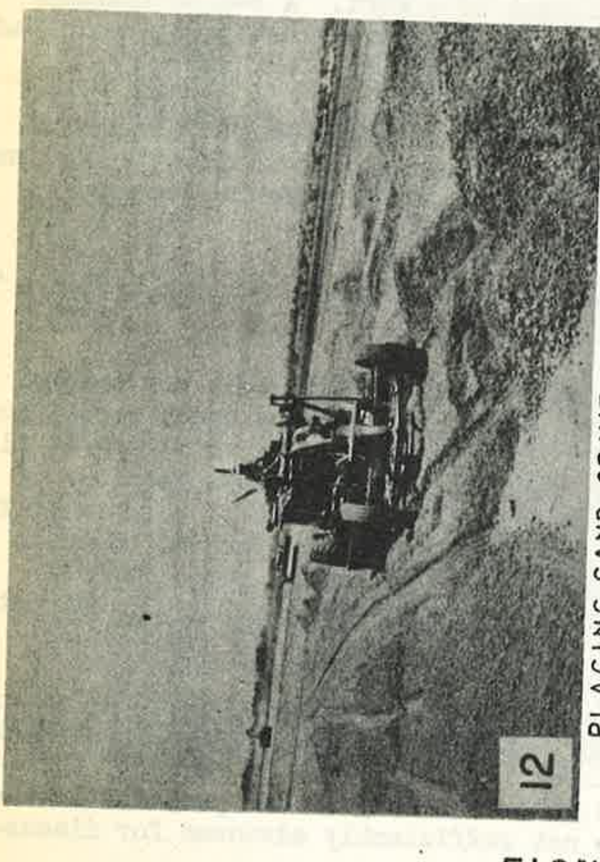
Planting was completed on 14 August 1945. A preliminary traffic test was made during April 1946 prior to the establishment of a turf. A second traffic test was conducted on 27 September 1946 using a C-46 aircraft having a wheel load of approximately 23,000 pounds.

The subgrade on which the runway shoulder is constructed has the lowest stability during periods of extreme moisture. For this reason traffic testing was performed following a prolonged wet period. Precipitation prior to testing is shown in Table 6.

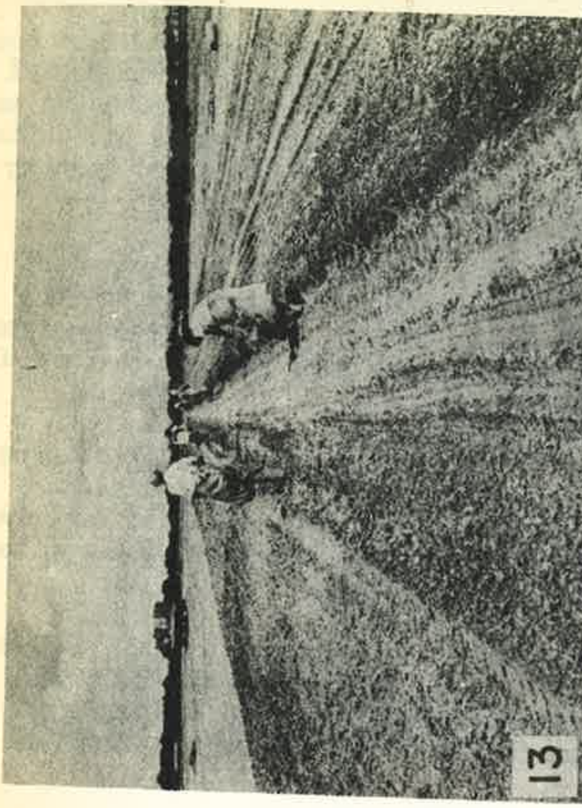
Moisture content of base and subgrade at time of test is given in Table 7. Density of the materials is shown in Table 8.

As at MacDill Field, the aircraft used for the traffic test was taxiied under its own power in a predetermined track pattern designed to apply repeat loading to the same area. Three lanes were laid out on each base material and 6, 11, and 16 passes, respectively, were made over the three lanes. Cross sections of the original ground line were made at 25-foot intervals for each of the six traffic lanes. Deformation measurements were made after 6, 11, and 16 passes. Results of these tests are illustrated graphically in Figure 16 and in the photographs in Figures 17 and 18. Note also the root penetration in the base materials evident in the photographs.

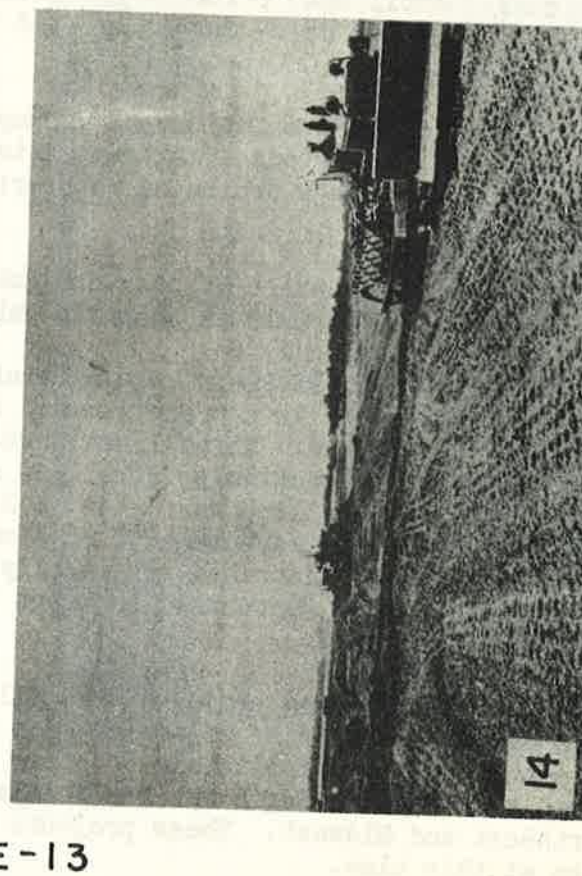
The foregoing projects have all been located in the warm humid region and have used Bermuda grass as the surface cover. Information gained from this work is not necessarily applicable to other grasses in other climatic regions, therefore, the Corps of Engineers has initiated other investigational projects in the Northeast and Midwest. These projects are not sufficiently advanced for discussion at this time.



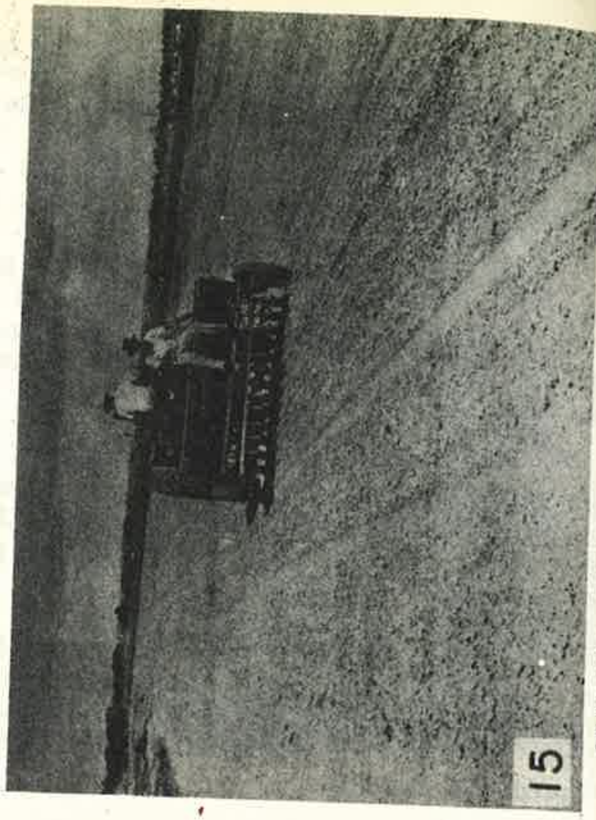
PLACING SAND GRAVEL BASE MATERIAL



PLANTING BERMUDA GRASS BEFORE COMPACTING



COMPACTING BASE PRIOR TO SEEDING



SEEDING BERMUDA GRASS ON SAND GRAVEL

FIGURE-13

TABLE 5

PHYSICAL PROPERTIES OF SUBGRADE AND BASE MATERIALS USED IN CONSTRUCTION OF TURF SHOULDER TEST SECTIONS AT MAXWELL FIELD, ALABAMA

Sample No.	Atterberg Limits L.L.	Atterberg Limits P.I.	Shrinkage Limit	Shrinkage Ratio	Modified AASHO Moisture	Modified AASHO Density
Subgrade						
1	24	7	19	1.81	11.3	121.7
2	32	10	23	1.64		
3	30	8	28	1.63	15.8	111.0
4	30	8	26	1.66		
5	33	11	23	1.75	13.6	115.8

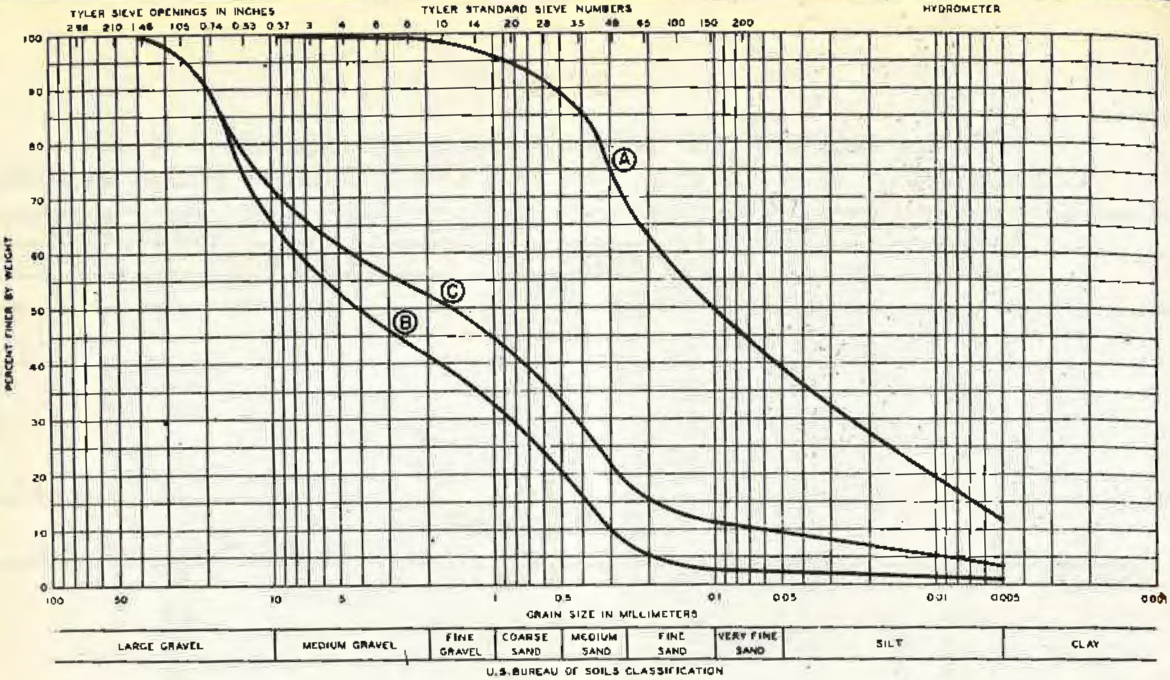
Base Materials	L.L.	P.I.	Shrinkage Limit	Shrinkage Ratio	% Material in Blend
Sand Gravel	19	0	23	1.46	81
Subgrade	20	2	17	1.84	19
Clay Gravel	41	15	21	1.67	90
Subgrade	28	3	28	1.56	10

Bases After Blending	L.L.	P.I.
Sand Gravel	20	3
Clay Gravel	32	7

TABLE 6

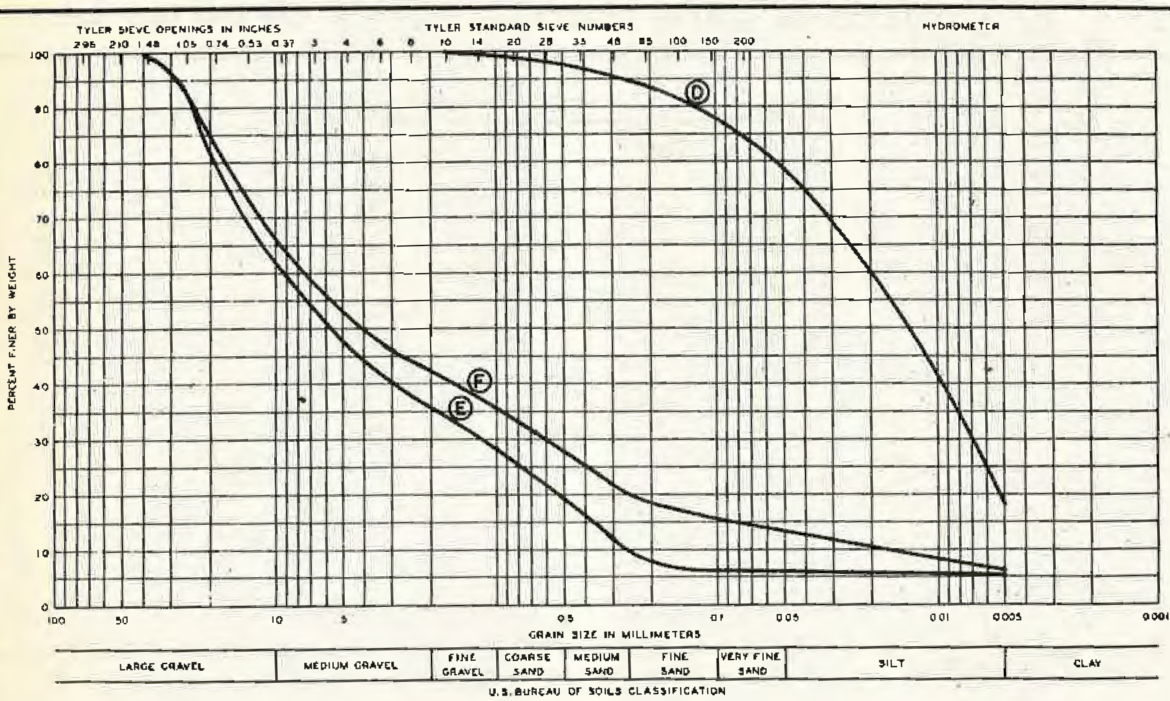
DAILY PRECIPITATION AT MAXWELL FIELD, ALABAMA, FOR A NINETEEN-DAY PERIOD IMMEDIATELY PRIOR TO TRAFFIC TESTING

Date	Precipitation
9 Sept 1945	.16
12 Sept	.62
15 Sept	1.03
16 Sept	.96
17 Sept	.14
23 Sept	1.13
24 Sept	.27
25 Sept	.98
Total	5.29



SAMPLE Ⓐ SUBGRADE
SAMPLE Ⓑ SAND GRAVEL
SAMPLE Ⓒ BLEND 19% Ⓐ AND 81% Ⓑ

FIGURE-14



SAMPLE Ⓓ SUBGRADE
SAMPLE Ⓔ CLAY GRAVEL
SAMPLE Ⓕ BLEND 10% Ⓓ 90% Ⓔ

FIGURE-15

TABLE 7

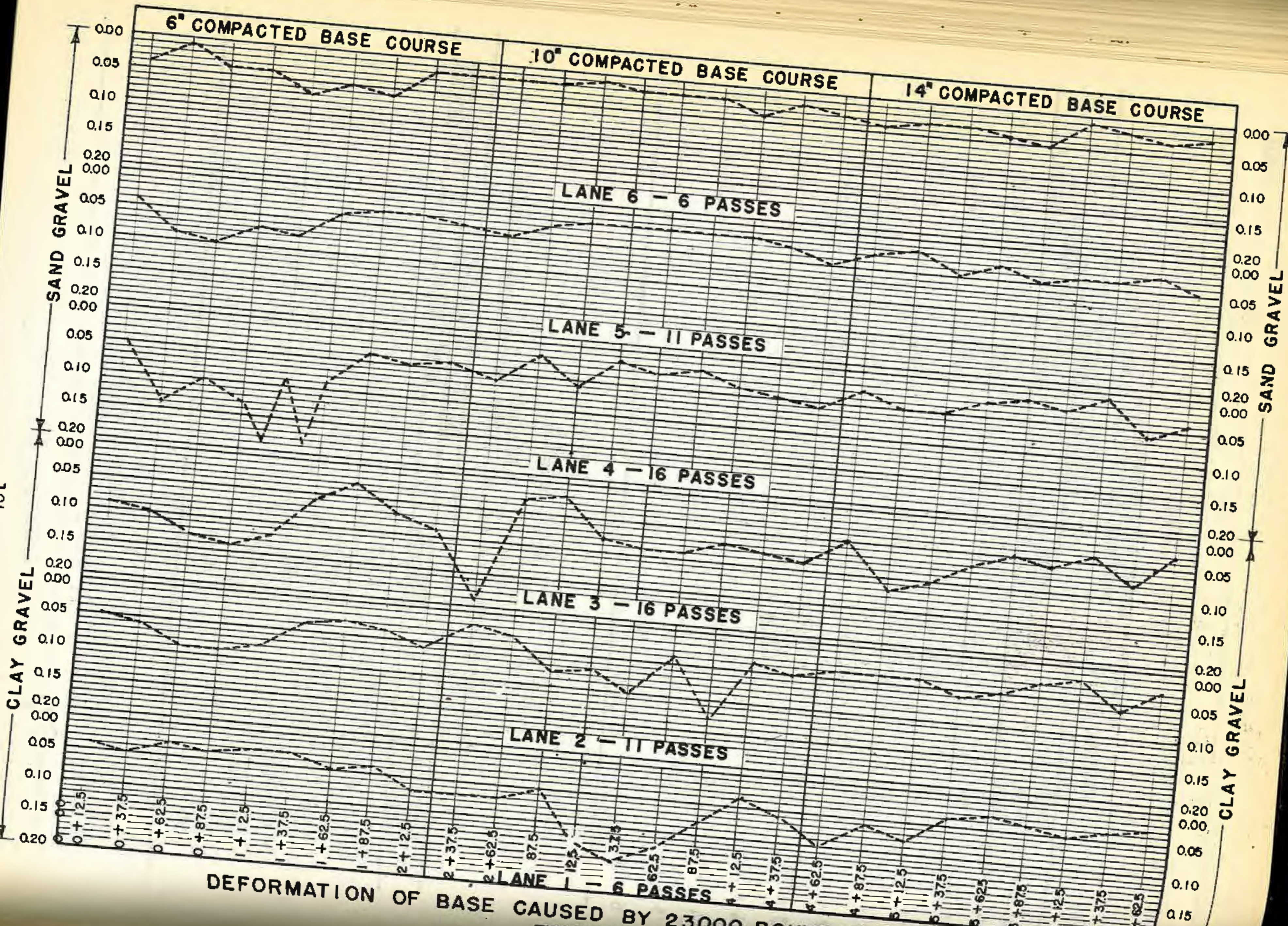
MOISTURE CONTENT OF SUBGRADE AND BASE OF MAXWELL FIELD TURF SHOULDER SECTION AT TIME OF TESTING

Station No.	Depth Base Course	Percent Moisture			
		Sand Gravel		Clay Gravel	
		Base	Subgrade	Base	Subgrade
0 + 38	6"	3.0	14.7	5.6	20.0
1 + 13	6"	4.1	16.2	6.7	15.1
1 + 38	6"	5.4	18.1	6.4	18.9
2 + 63	10"	7.0	19.6	9.1	22.0
3 + 38	10"	9.5	19.8	10.3	25.6
4 + 13	10"	8.8	20.7	7.8	25.0
4 + 88	14"	8.4	21.6	9.8	24.8
5 + 63	14"	7.7	11.9	8.9	24.6
6 + 38	14"	10.4	22.7	10.9	22.7

TABLE 8

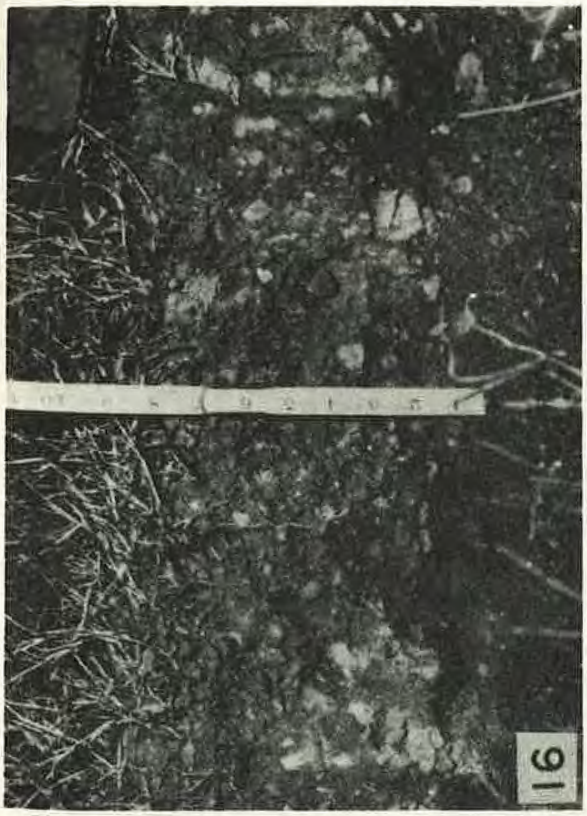
TYPICAL DENSITIES OF BASE AND SUBGRADE OF MAXWELL FIELD TEST SECTION, ALABAMA

Location Sample	Density of Material		
	Subgrade	Sand Gravel	Clay Gravel
3 + 10	83.3	97	95
3 + 85	87.7	97	95
4 + 60	80.1	100	96
5 + 35	75.7	97	
6 + 10	92.8	97	90

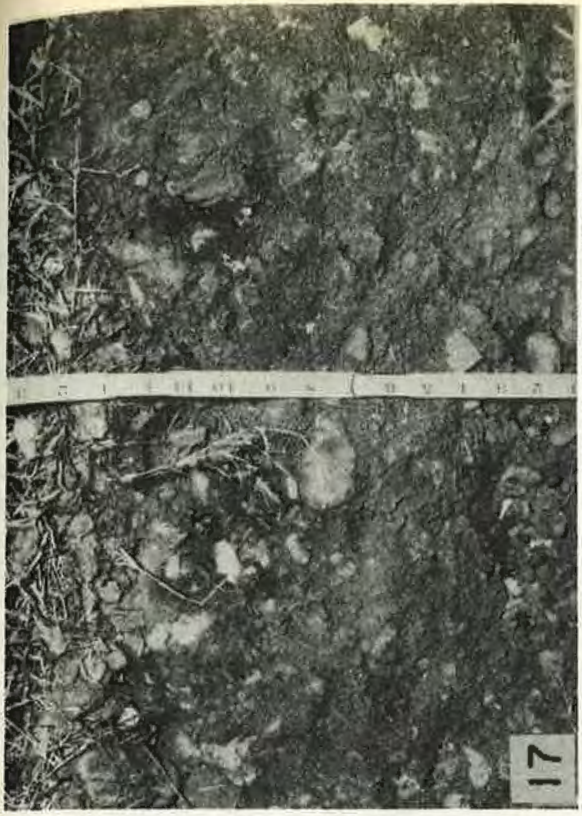


DEFORMATION OF BASE CAUSED BY 23,000 POUND WHEEL LOAD

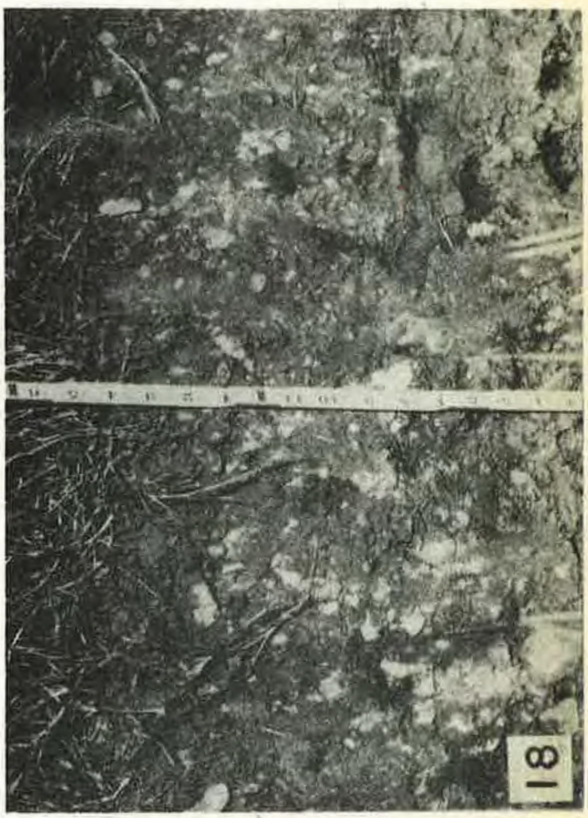
FIGURE 16



6 INCH CLAY GRAVEL BASE



10 INCH CLAY GRAVEL BASE



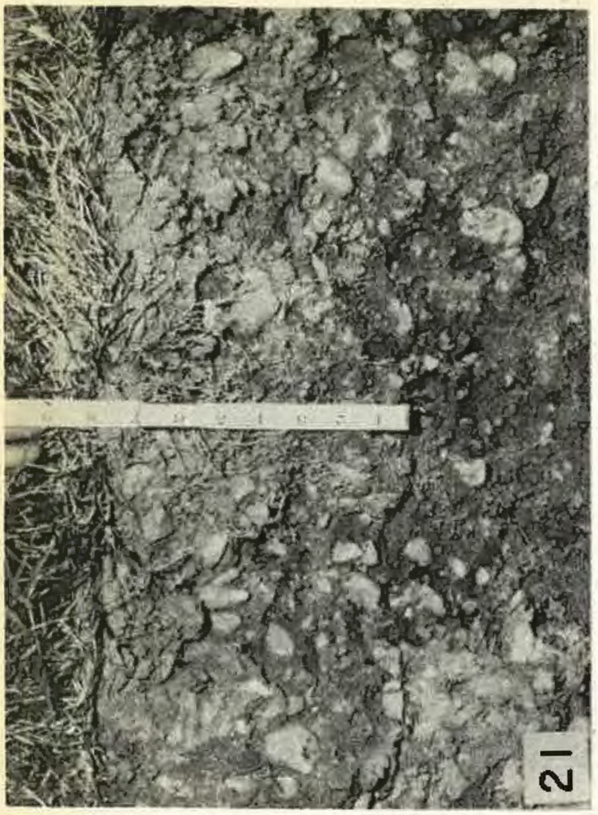
14 INCH CLAY GRAVEL BASE

23,000 LBS.

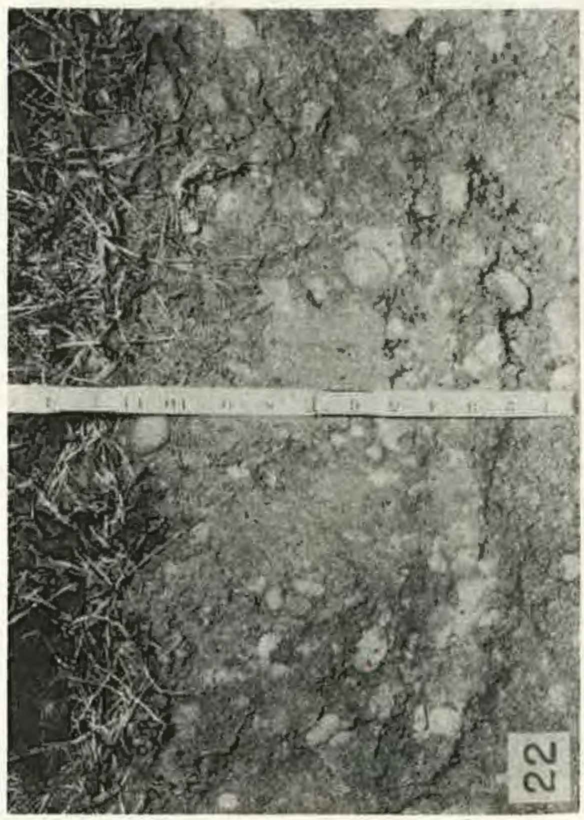
TRAFFIC LANE - 6 INCH CLAY GRAVEL

FIGURE-17

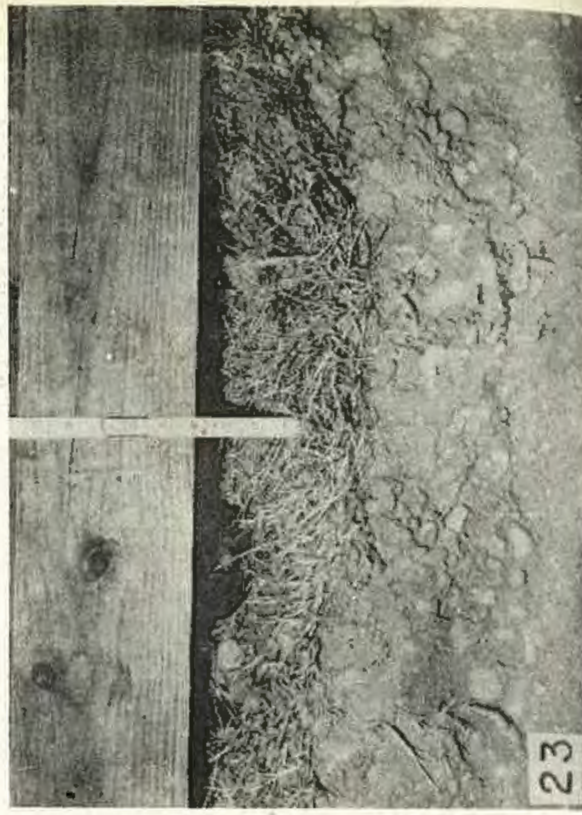
6 INCH SAND GRAVEL BASE



10 INCH SAND GRAVEL BASE



14 INCH SAND GRAVEL BASE



23,000 LB. LOAD TRAFFIC LANE - 6 INCH SAND GRAVEL

FIGURE-18

Summary - Stabilization of Florida sands by the blending of approximately equal quantities of limerock and sand to a combined depth of six inches produced sufficient load bearing capacity to support aircraft of approximately 65,000 pound wheel load, or the B-29 class. Mixtures of sand clay, limerock, and sand also provided sufficient stability. The poor quality of the locally available sand clay made this material less desirable and its use was limited to a relatively few fields.

The incorporation of large quantities of infertile stabilizing materials increased proportionately the natural infertility of the native soils. For this reason increased applications of fertilizer were necessary. Observation of results of fertilizer practices and of field tests on stabilized soils indicated that Bermuda grass responded principally to nitrogen. Additional applications of phosphorous and potash, after the initial application of a complete goods, did not produce an appreciable increase in growth, nor did minor elements appear to affect its growth. These results were also characteristic of Bermuda grass on the natural soils. The only apparent change in nutritional characteristics of the bases was a proportionate decrease in fertility.

No particular difficulty was encountered in establishing turf on the stabilized soils. Vegetative planting and seeding were equally effective provided ample moisture was present. Vegetative planting produced better results during periods of low rainfall. This was apparently because the sprigs were planted below the approximate two-inch layer of dry surface soil characteristic of the area during dry weather.

Results of constructing and testing a special test section at MacDill Field on a ball bearing sand subgrade indicate that local sand-clay placed as an eight-inch blanket had less bearing capacity than an adjacent six-inch layer of blended sand and limerock. Deformation of the sand-clay was progressively greater with an increase in moisture content, and consisted of lateral displacement of the base material. Only slight consolidation of the subgrade was apparent under either sand-clay or limerock base.

Establishment of turf from seed on the sand-clay was not successful, apparently because of displacement of seed by wind and water action. There was no apparent difference in fertilizer requirements on the two materials.

Similar tests were conducted at Maxwell Field on a plastic subgrade using clay gravel and sand gravel as base materials with Bermuda grass for dust and erosion control. Equal results were obtained from sprigs and seed on each of the bases. Most efficient use of fertilizer occurred on the less porous clay-gravel base. Reaction to loading was similar to that of the sand-clay base at MacDill Field; deformation was greater on areas having a higher moisture content. Some slight failure of subgrade occurred under the six-inch bases. All thicknesses of each material were adequate for a limited number of load applications from aircraft of the C-46 or 25,000 pound wheel load class.

In none of the above tests was there any apparent correlation between compactive effort and turf production, nor between turf density and load supporting capacity. Deformation increased progressively with the number of load

applications, with least increase in deformation occurring on the limerock base. Little or no compaction differential remained after a year's weathering and growth of grass.

While no accurate root penetration determinations were made, observation of root development in walls of observation trenches indicated that root penetration varied from about five inches in the limerock base to about ten inches in the sand-gravel base.

Additional investigations have been initiated to study the development of turf on stabilized bases in other climatic regions. These studies are not sufficiently advanced to justify discussion at this time. It is interesting to note, however, that turf grasses indigenous to cool humid climates have been established on various aggregate base materials, with and without the addition of soil particles in the silt and clay ranges.

It is evident from studies to date that, by proper cultural methods, turf can be developed on practically any base designed for load bearing capacity. It is hoped that on completion of the studies now in progress the Corps of Engineers will be able to formulate design criteria for the development of turf covered, stabilized bases having adequate bearing capacity to support any probable load resulting from aircraft or other vehicle operation.

DISCUSSION OF REPORT BY CALE

(Questions were addressed to the author, unless otherwise indicated)

Was there any maintenance of the shoulder material carried out?

> No rolling or recompaction was done except for the benefit of the turf and except that ruts caused by traffic near the pavement were filled.

Were scarred areas replanted, or is Bermuda grass rapidly self-healing?

> No replanting was needed even where scars 12 in. wide were made by planes landing, unless there was a severely deep disturbance of the soil.

How deep was fertilizer incorporated in the initial application?

> A complete fertilizer was applied prior to final mixing and blading and incorporated 3 in. to 4 in. deep. Later applications of soluble fertilizers were made on the surface.

One soil reported had very coarse aggregate underneath the wearing course. How great a volume of soil is required to support plant life when underlain by non-capillary granular material?

> Fescue on the above soil was brown in the dry summer months but not dead. Ability of grass to survive under this condition depends on many factors; for example, the ability of the soil to retain water and nutrients. This particular soil was 7 to 8 in. in depth. It is not a healthy condition. A progressive variation of material from the coarse aggregate of the base to the fine material of the wearing course would be better for plant life.

Does topsoil decrease stability?

> There has been a lot of theorizing on this point. The work covered by this report dealt with other materials. Dr. Mott (Purdue) in his experiments added some soil fines to aggregate material with good results, with greatest strength obtained with 5 percent to 15 percent soil fines. The peak was at about 12 percent fines. No topsoil, as the term is generally understood, was used. (Mr. Iurka) "Topsoil" is a term we should forget in this work. The soils engineers have a terminology which they recognize and which we can and should use.

Is there need for repeated loads in the same wheel track in making traffic tests on shoulders?

> The probability of repeat impacts by planes landing is remote except in some concentrated landing areas. These tests were rather theoretical, with loads repeated until failure.

How can bearing value of roots be measured?

> Although there is an apparent increase of bearing value due to vegetation, this value seems relatively unimportant when loads of 60,000 lbs. are concerned.

(Addressed to Mr. McAlpin) Is density related to bearing value?

> There is a definite relation of density to bearing value.

(Addressed to Mr. McAlpin) In compacting shoulders can density be made greater than natural? Will the increased density be lost due to weathering and plant growth? Increased density increased the difficulty of establishing vegetation, so if some density will be lost by weathering or plant growth, why get maximum density initially?

> Density can be made greater than natural. Sandy materials would retain their density but more plastic material would lose some density through weathering. A light type roller could be used in the spring when the soil is moist to compact the wearing course.