Effect of Density and Moisture on Consolidation of Compacted Soil

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This paper reports an investigation of the consolidation that takes place in a compacted soil under specific density and moisture content. Seven representative soil samples ranging from fine sand to clay were selected from the 45 major soil series in the United States. Four tests were made with different density or moisture for each sample.

The results were analyzed and correlated in a number of basic diagrams of the consolidation stress-strain relations. The time-consolidation curves and consolidation stress-strain curves at various densities and moistures are given to show the relationship between the displacement and the applied loading. From these the settlement of the soil under pressure in the field can be predicted. By comparing these different curves, the relative sensitivity of soils when encountering water and external pressure can be obtained.

These curves indicate that soils at maximum dry density and optimum moisture have the minimum consolidation. Settlement for sand is very small compared to that for clayey soils. Clay samples showed a wide range of volume change.

• SOIL is compacted to increase its strength and decrease its volume change. The required density is usually specified to a certain percentage of the maximum by AASHO Method T 99. As an aid in determining the required density, consolidation tests at three moisture contents and two densities were run on seven soils ranging from sand to a very plastic clay.

DESCRIPTION OF MATERIALS

The materials tested were Houston black clay, Davidson clay loam, Williams loam, Sharpsburg silt loam, Portneuf silt loam, Ruston loamy sand, and Lakewood fine sand. They were selected from a group of 45 soil samples and identified by the Soil Conservation Service of the U.S. Department of Agriculture. The soil samples have been used in the testing program of the Bureau of Public Roads, and were air-dried at 140 F.

Classification and compaction tests of these seven soil samples have been performed by the laboratory of the Bureau of Public Roads. The results of these tests are given in Table 1 and Figure 1. The compaction curves are given in Figure 2. For brevity, the soil type is referred to by its first name only.

Estimated compressibility and permeability are based on the Unified Classification determined by the Bureau of Public Roads.

Houston black clay is a combination of two samples with similar characteristics. It is an inorganic clay of high plasticity and dry strength. It also has high shrinkage, expansion and elasticity. In other

TABLE 1

CHARACTERISTICS AND COMPACTION[1] RESULTS OF THE SEVEN SOILS (REFERRED TO IN FIGURE 2)

Curve	Soil Type	BPR No.	State Where Sampled	Classification		Sp. Gr.	Consistency Limit (%)			ASTM Grain-size Distribution (%)			Shrinkage		Opt. Moist. (%)	Max. Dry Density (pcf)
				AASHO	Unified		Liquid Limit	Plastic Limit	Plasticity Index	Sand	Silt	Clay	Limit	Ratio		
A	Houston black clay	S29099[2] S29109[2]	Tex.	A-7-5 (20)	CH	2.68	70	30	40	17	33	50	9	2.06	24	97
B	Davidson clay loam	S30261	Va.	A-7-5 (20)	MH	2.89	72	37	35	6	12	82	24	1.60	31	89
C	Williams loam	S30038	N.D.	A-6 (12)	CL	2.73	38	20	18	28	32	40	16	1.80	17	108
D	Sharpsburg silt loam	S30910	Iowa	A-7-6 (18)	MH-CH	2.74	56	28	28	3	50	47	13	1.90	22	97
E	Portneuf silt loam	S30470	Idaho	A-4 (8)	ML-CL	2.72	26	22	4	10	68	22	19	1.73	16	107
F	Ruston loamy sand	S30065	Ga.	A-7-6 (7)	SC	2.69	42	21	21	53	5	42	19	1.72	19	108
G	Lakewood fine sand	S32808	Fla.	A-3 (0)	SP	2.63	NP	NP	NP	98	1	1	NP	NP	16	102

[1] Tested in accordance with AASHO Designation T 99-49.
[2] Combined sample.

words, it is extremely sensitive in volume change due to the effect of water. The permeability of this soil is low, but the compressibility is high.

Davidson clay loam is an organic silt and silty clay. The moisture content in this soil is a large percentage, and the shrinkage limit is rather high. It has similar characteristics to the previous soil, but has a medium dry strength instead of high, and also the drainage characteristics are better.

According to the AASHO Classification, this sample is classified as A-7-5 (20) which indicates that it has a large portion of clay and behaves as a clay. The fact is that the Unified Classification of this soil is located very closely to the boundary line between classes CH, MH. However, it is quite possible that the characteristics of CH are predominant.

Williams loam is an inorganic silty and sandy clay of medium plasticity and compressibility. Its dry strength is from medium to high, and the permeability is low.

Sharpsburg silt loam is an organic elastic silt and silt-clay with some inorganic clay of high plasticity. It has a medium dry strength and a high compressibility. The drainage characteristics are poor, but better than the foregoing three soils.

Portneuf silt loam is a slightly plastic soil of organic and inorganic silt and silty clay. It has a very small volume change; in other words, it has slight shrinkage, expansion and elasticity, and its compressibility is relatively low. The permeability is fair in this soil: therefore, it takes a shorter period for consolidation.

Ruston loamy sand is an inorganic sandy clay of medium plasticity and compressibility. It has very slight shrinkage, expansion and elasticity. The drainage characteristics are poor. This soil has a character somewhere between sand and clay.

Lakewood fine sand is a nonplastic,

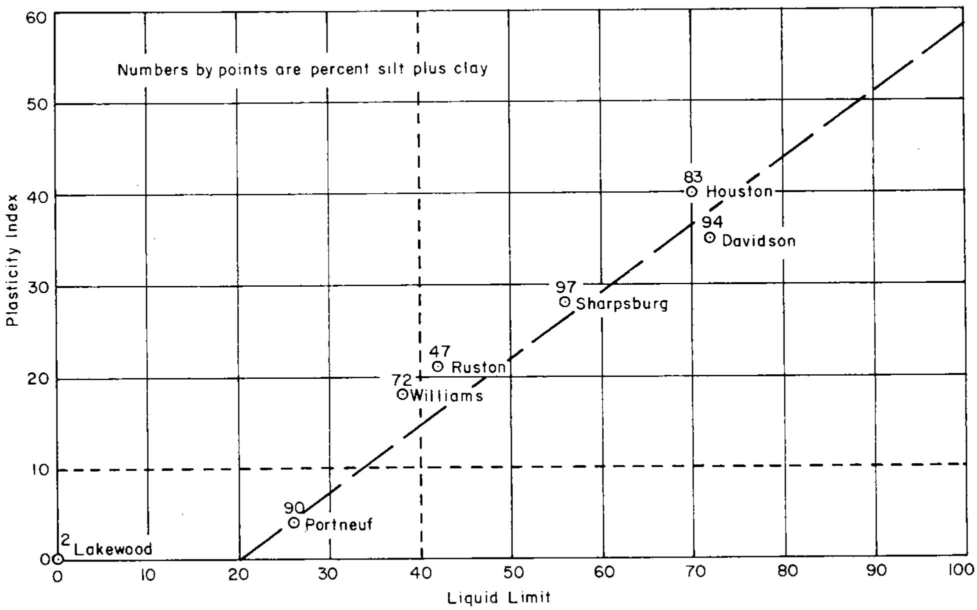

Figure 1. Plasticity test results.

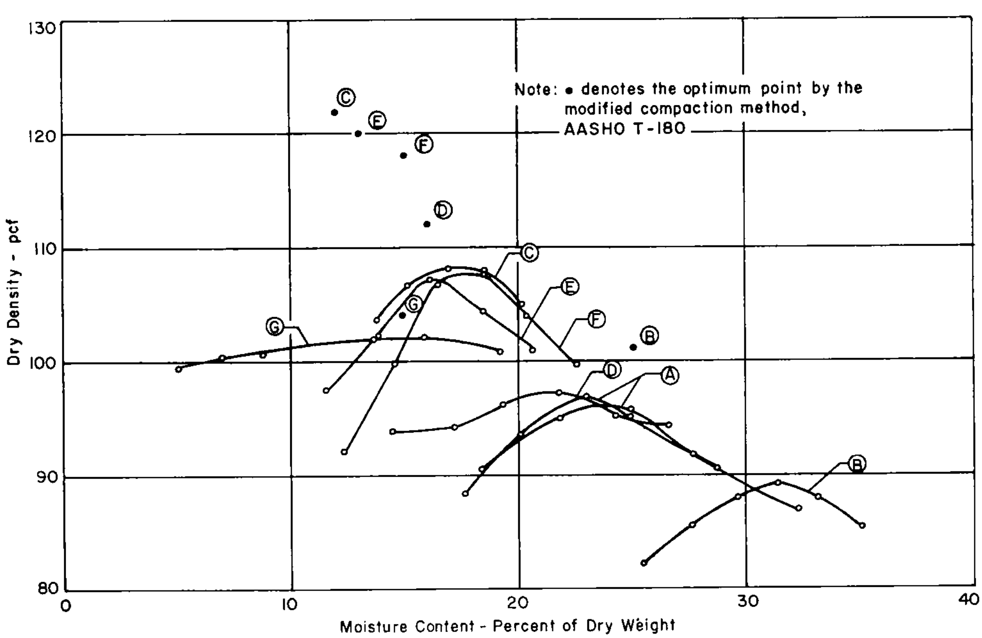

Figure 2. Moisture-density relationships for seven soils.

poorly-graded fine sand without dry strength. It has almost no shrinkage, expansion and elasticity. Below saturation, the phenomenon occurring in this soil when encountering water is just opposite to the clay or clayey soils. Increasing its moisture will not increase its volume but may make it more dense. The permeability of this soil is excellent; it takes only a short period for consolidation.

The Sharpsburg and Lakewood have a wide range of percentage of moisture content in compaction.

TEST PROCEDURE

Four conditions of each sample were taken (Table 2) from the density-moisture curves. The maximum dry density at optimum moisture was chosen as a basic condition, then the same optimum moisture but 95 percent of the maximum dry density was used. This density intersects the compaction curve at two different moisture contents—one more, the other less, than the optimum moisture. The Sharpsburg was the exceptional sample in selecting the moisture contents in conditions 3 and 4, because its compaction curve did not follow the same pattern as the other soils. In this case, the 95 percent density did not intersect the compaction curve. Therefore, the selected moisture contents, either wetter or drier than the optimum, could not be based on the same principle, and were chosen 5 percent and 9 percent less than the optimum by following the shape of the compaction curve approximately.

In specimen preparation, the samples were pulverized by a rotating drum containing a number of rubber rollers (*1*), then checked for natural moisture content. The specimen was 1¾ in. in diameter and ½ in. thick, rather small for use in the small consolidometer used.

Because specific dry density and moisture were required for each specimen, a special compaction procedure was necessary before the consolidation testing began. A certain weight of the pulverized soil and a certain amount of water were mixed and placed in the consolidometer for compaction. For convenience, a CBR loading apparatus was used to compact the sample.

Consolidation Test

The specimen was tightly fitted into a solid brass ring, which was placed on a base consisting of a porous stone in a brass base of the same diameter as the specimen. The top surface of the specimen was covered by another porous stone and a brass cylinder fitting the ring was connected to the ring. A loading piston with a cover plate was then placed on top of the upper porous stone. The assembly was clamped to the base by means of two tie rods.

TABLE 2
CONDITIONS OF DENSITY AND MOISTURE CONTENT FOR TESTING

	Conditions[1]							
	1		2		3		4	
Soil Type	D	M	D	M	D	M	D	M
Houston	97	24	92	24	92	27	92	19
Davidson	89	31	85	31	85	35	85	27
Williams	108	17	103	17	103	21	103	14
Sharpsburg	97	22	92	22	92	27	92	13
Portneuf	107	16	102	16	102	20	102	14
Ruston	108	19	103	19	103	21	103	15
Lakewood	102	16	97	16	97	22	97	3

[1] D denotes dry density in pcf; M, moisture content in % of dry weight.

The load was applied through a beam placed directly on top of the piston. The compression of the soil was measured by an extensometer dial graduated to 0.001 in.

After assembling the consolidometer and loading device, the first load of 0.5 kip per sq ft was applied, dial readings were taken at 0, 1/9, 1/4, 1, 4, 9, 16, 25 min and a convenient interval progressively until complete consolidation. The specimen under the first loading test was at its specific density and moisture. Before the second load was applied, water was poured into the two standpipes of the base to keep the sample saturated. The openings of the standpipes were covered during testing so that some free water could be maintained over the surface of the sample to prevent drying due to evaporation.

Time was allowed for the specimen to swell by saturation. Then the second load was applied and readings were again taken. The other loads were added in steps. The consolidation pressures were applied in five convenient increments until the maximum pressure of 16 kips per sq ft was reached. Each load increment is equal to the previous total load. The load was applied slowly for two reasons: (a) to avoid the shock effects if the load were applied suddenly; (b) because in practice, the load on the soil builds up gradually with the progress of construction.

To obtain complete consolidation of the soil under the different consolidation pressures, each load increment was allowed to remain for a minimum time of a few minutes for sand and 24 hr for clay before the next load was applied. The 1-day duration is commonly used for clays for obtaining primary consolidation.

TEST RESULTS

The consolidation test results are given in Table 3 and shown in Figures 3 through 14. Complete time-consolidation data have previously been given by Cheng (*3*). Two relationships are shown: the time-consolidation relationship and the stress-strain relationship.

In the stress-strain diagrams, the strain is expressed by

$$\text{Strain} = \frac{\text{Initial thickness—Final dial reading for each load}}{\text{Initial thickness}} \text{x } 100 \quad (1)$$

The initial thickness is 0.5 in. for all specimens.

It should be noted that a test on the Portneuf silt loam (density 102 pcf., moisture 20 percent has been repeated, and the results checked with the previous test. The repeated data are given in Table 3 and shown in Figure 11.

Test results are presented by two kinds of curves. Figures 3 through 6 represent the relationship between the thickness and the logarithm of the time with different consolidation pressures.

Figures 7 through 14 represent the strain against pressure. This representation expresses the consolidation behavior of the selected soils at various densities and moistures.

DISCUSSION OF RESULTS

To point out the basic factors affecting the stress-strain relationship for the selected soils and for those soils having similar characteristics and properties, discussion and interpretation of the test results are needed. The density and moisture of the soil are the focus for discussion.

The consolidation of all samples is rather rapid for loads below 8 kips per sq ft. Time-consolidation curves for loadings less than 8 kips are not shown. Under heavier loads (8 and 16 kips per sq ft), the shape of the curves depends on the character and properties of the soil: the curves of

TABLE 3

REDUCTION[a] IN THICKNESS (%) UNDER DIFFERENT PRESSURES

Soil Type	Dry Density (pcf)	Moisture Content (%)	Pressure (kips/sq ft)											
			0.5	1	2	4	8	16	8	4	2	1	0.5	0.02
Houston	97	24	0.34	−5.74	−5.46	−4.80	−2.76	1.05	0.45	−0.36	−1.02	−2.00	−2.74	−4.36
	92	24	0.66	−4.14	−3.80	−2.86	−0.18	5.45	5.02	4.33	3.65	3.36	3.34	3.08
	92	27	0.60	−2.83	−2.62	−2.04	−0.08	4.52	4.10	3.37	2.55	1.76	1.40	0.61
	92	19	0.20	−8.54	−7.80	-5.46	−0.20	6.42	5.82	4.96	4.26	3.64	3.00	0.75
Davidson	89	31	0.30	−0.25	−0.18	0.08	1.26	6.78	6.58	6.24	6.18	6.16	6.15	6.12
	85	31	0.39	0	0.13	0.69	4.76	11.24	11.04	10.79	10.54	10.35	10.10	9.96
	85	35	0.24	0.25	0.48	1.56	7.52	12.94	12.70	12.42	12.19	12.01	11.82	11.60
	85	27	0.27	−0.30	−0.03	1.04	7.36	12.72	12.50	12.27	12.02	11.80	11.74	11.36
Williams	108	17	0.62	−0.08	0.24	1.02	3.08	7.40	7.38	7.07	6.62	6.24	5.84	5.40
	103	17	0.40	−0.27	0.42	1.92	6.44	11.29	11.15	10.92	10.63	10.30	10.01	9.24
	103	21	1.24	0.88	1.22	2.60	6.76	11.32	11.18	11.00	10.58	10.30	9.93	9.20
	103	14	0.33	−1.06	−0.42	2.52	7.97	12.69	12.47	12.22	11.76	11.59	11.42	10.24
Sharpsburg	97	22	0.24	−2.34	−2.03	−1.20	1.20	6.44	5.98	5.40	4.88	4.36	3.66	2.52
	92	22	0.56	−1.60	−1.20	0.18	5.02	10.62	10.40	9.84	9.30	8.46	8.28	7.14
	92	27	0.50	0.02	0.35	0.99	4.40	10.76	10.38	9.75	9.19	8.41	7.64	7.18
	92	13	0.02	−4.72	−3.60	0.43	6.40	12.00	11.74	11.16	10.84	10.50	10.10	9.02
Portneuf	107	16	0.04	0	0.16	0.38	0.66	1.24	1.16	1.00	0.86	0.70	0.46	0
	102	16	0.10	−0.03	0.15	0.48	0.88	2.56	2.26	2.08	1.93	1.74	1.48	0.94
	102	20	0.57	0.66	1.13	2.01	4.30	7.38	7.18	6.84	6.61	6.38	6.16	5.24
	102	20[b]	0.42	0.58	1.06	1.82	3.88	7.26	—	—	—	—	—	—
	102	14	0.03	−0.16	0.02	0.24	0.49	1.74	1.61	1.53	1.42	1.21	1.14	0.46
Ruston	108	19	0.17	0	0.10	0.26	0.46	1.22	1.12	0.96	0.80	0.71	0.59	0.46
	103	19	0.07	0.07	0.19	0.41	1.80	7.44	7.24	7.10	6.97	6.84	6.76	6.48
	103	21	0.20	0.18	0.29	0.80	2.27	7.70	7.56	7.39	7.20	7.09	7.02	6.76
	103	15	0.16	−0.30	−0.11	0.52	2.00	6.96	6.91	6.80	6.63	6.57	6.48	6.22
Lakewood	102	16	0.05	0.10	0.15	0.24	0.35	0.50	0.42	0.36	0.28	0.24	0.20	0.14
	97	16	0.15	0.28	0.47	0.69	0.96	1.27	1.10	0.93	0.84	0.76	0.72	0.58
	97	22	0.22	0.48	0.79	1.04	1.41	2.00	1.80	1.62	1.49	1.40	1.36	1.22
	97	3	0.16	0.28	0.44	0.74	1.10	1.48	1.37	1.22	1.17	1.08	1.02	0.91

[a] Minus sign indicates increase in thickness of specimen.
[b] Test repeated for checking.

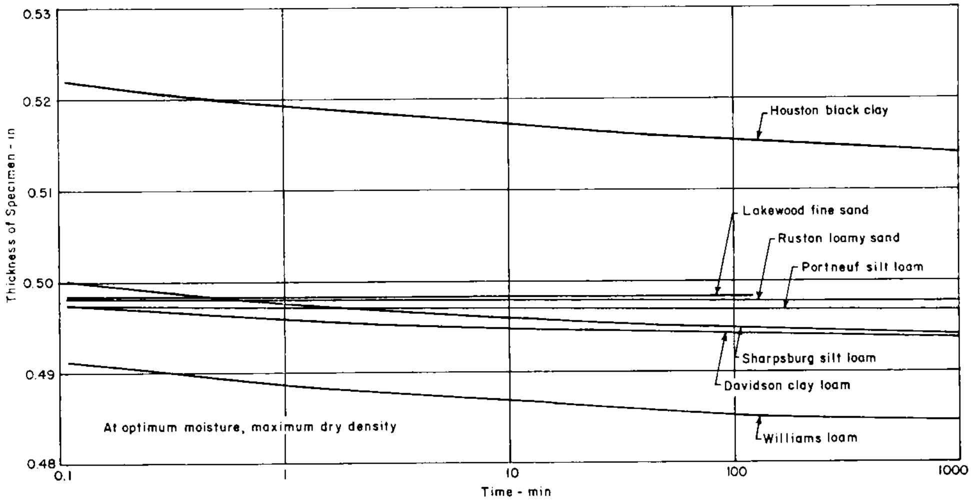

Figure 3. Time-consolidation curves for 8-ksf pressure.

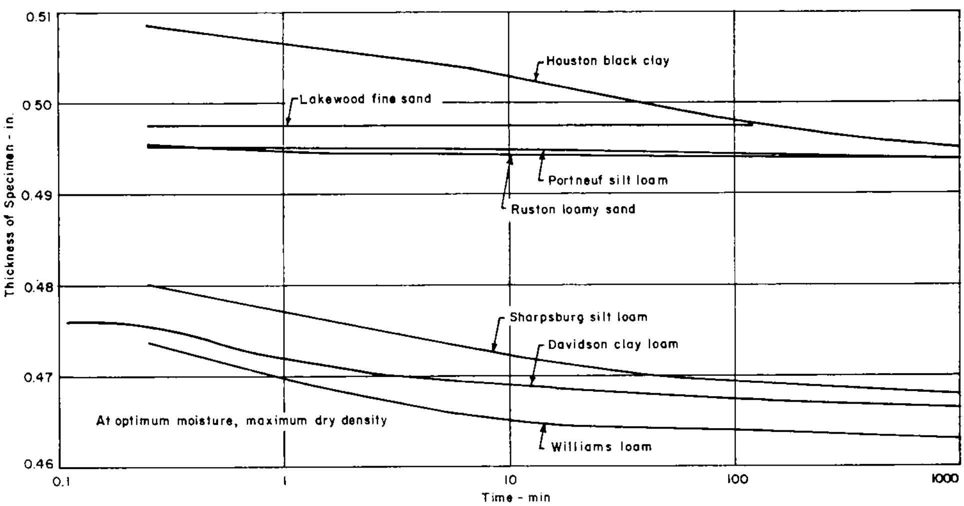

Figure 4. Time-consolidation curves for 16-ksf pressure.

elastic materials, such as Houston, Davidson, Williams and Sharpsburg, show a characteristic pattern (Figs. 3 and 4). Because the four groups of curves of various conditions follow a general pattern for each sample, only the group of curves at maximum density and optimum moisture is presented for all soils. For Houston and Davidson, at a heavier load of 8 kips per sq ft, four curves representing the four conditions are shown to give a general picture of the rate of consolidation (Figs. 5 and 6). In material like clay, the initially drier sample consolidates more rapidly than the others after it is saturated. This phenomenon is not true for Davidson, which shows that the wetter sample has this character.

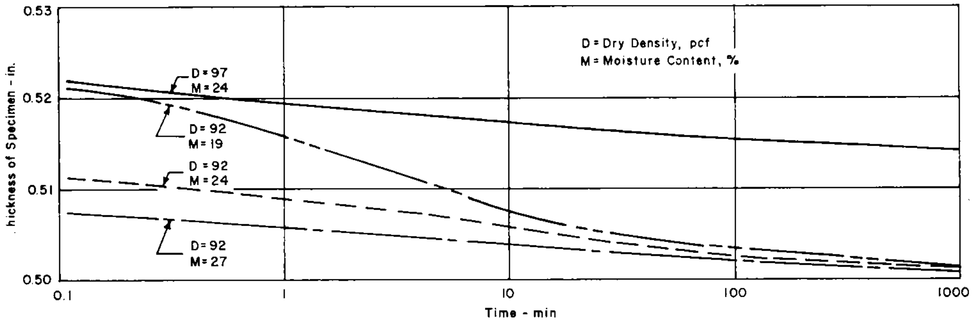

Figure 5. Time-consolidation curves for Houston black clay.

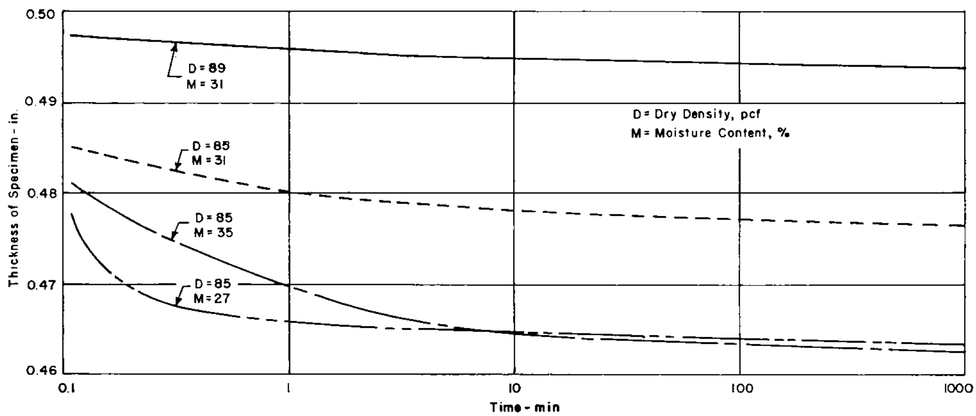

Figure 6. Time-consolidaton curves for Davidson clay loam.

With the time-consolidation data, the coefficient of consolidation C_v, which indicates the rate of compression under a load increment, can be computed by applying the square-root fitting method. When the applied loads are less than 4 kips per sq ft, the curves are rather flat, and at the application of the maximum load, the specimen consolidates so rapidly that it is difficult to obtain the $\frac{1}{9}$-min dial reading for some samples. In such a case, the dial readings under a load increment from 4 to 8 kips per sq ft are most convenient for furnishing the values of C_v. For cohesiveless soil, such as sand, the 90 percent consolidation occurs very rapidly (at about $\frac{1}{9}$ min); therefore, the C_v value of sand is not shown. Some C_v values of the six soils are given in Table 4.

Table 3 indicates the relationship of the variation of density and moisture with consolidation under each load for the seven types of soil. However, the stress-strain curves of Figures 7 through 14 express the comparison between the different conditions more clearly. One unloading curve for each soil is plotted for reference on the shape of these curves.

In analyzing the stress-strain curves with the data from Table 3, the general phenomena for all the soil samples and some particular characteristics in consolidation for each soil will be discussed.

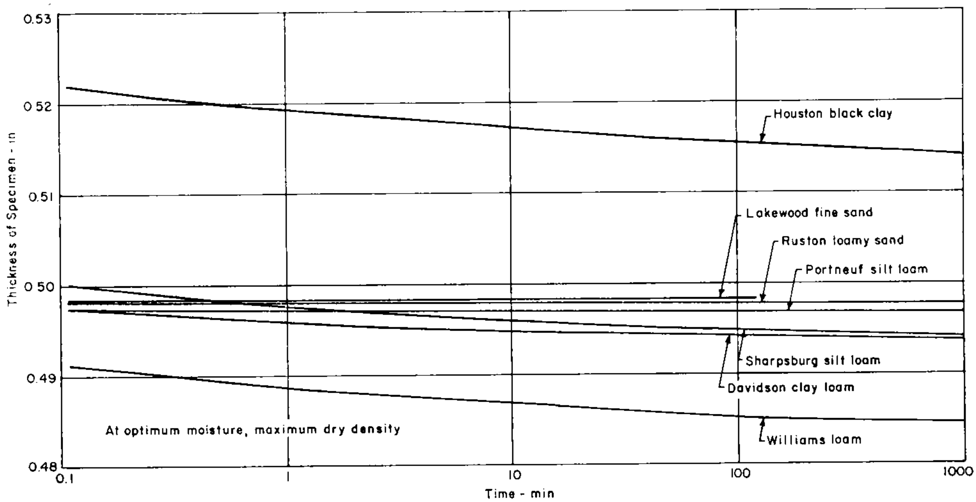

Figure 3. Time-consolidation curves for 8-ksf pressure.

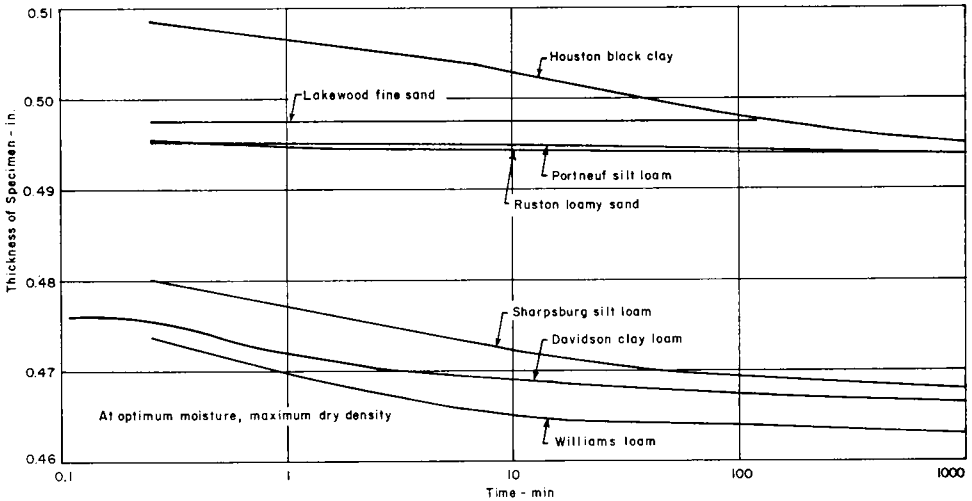

Figure 4. Time-consolidation curves for 16-ksf pressure.

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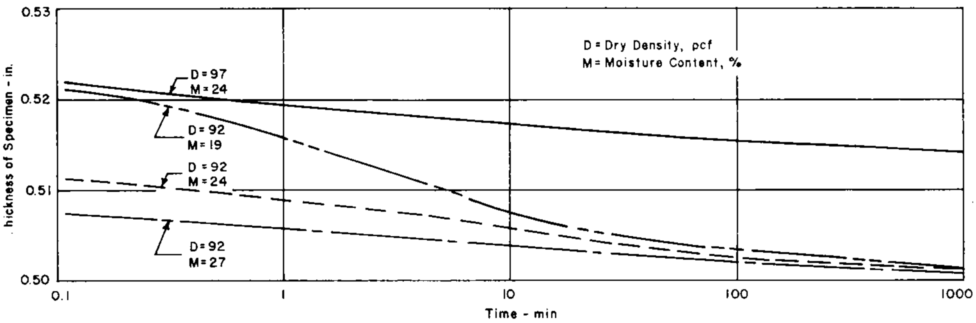

Figure 5. Time-consolidation curves for Houston black clay.

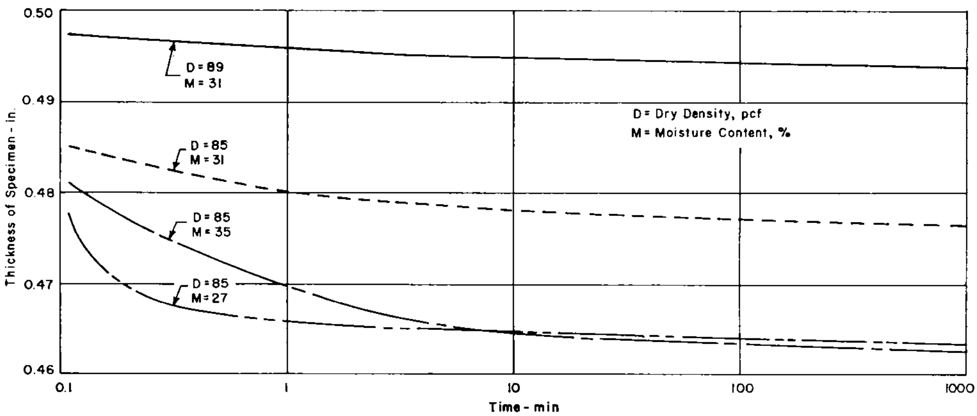

Figure 6. Time-consolidaton curves for Davidson clay loam.

With the time-consolidation data, the coefficient of consolidation C_v, which indicates the rate of compression under a load increment, can be computed by applying the square-root fitting method. When the applied loads are less than 4 kips per sq ft, the curves are rather flat, and at the application of the maximum load, the specimen consolidates so rapidly that it is difficult to obtain the 1/9-min dial reading for some samples. In such a case, the dial readings under a load increment from 4 to 8 kips per sq ft are most convenient for furnishing the values of C_v. For cohesiveless soil, such as sand, the 90 percent consolidation occurs very rapidly (at about 1/9 min); therefore, the C_v value of sand is not shown. Some C_v values of the six soils are given in Table 4.

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TABLE 4

COEFFICIENT OF CONSOLIDATION BY SQUARE ROOT FITTING METHOD APPLIED PRESSURE 4-8 KIPS PER SQ FT

Soil Type	Density (pcf)	Moisture (%)	H (in.)	Fitting Time, t_{90} (min)	C_v, $0.848H^2/t_{90}$ (ft²/day)
Houston	97	24	0.5240	0.6084	3.8
	92	24	0.5143	0.0400	56.1
	92	27	0.5102	0.0272	81.1
	92	19	0.5273	0.1060	22.2
Davidson	89	31	0.4996	0.0625	33.9
	85	31	0.4966	0.0306	68.2
	85	35	0.4922	0.3906	5.2
	85	27	0.4948	0.3600	8.0
Williams	108	17	0.4949	0.0729	28.5
	103	17	0.4904	0.3249	7.4
	103	21	0.4870	0.4030	5.0
	103	14	0.4874	0.2401	8.4
Sharpsburg	97	22	0.5060	0.0676	32.2
Portneuf	107	16	0.4981	0.0225	93.5
Ruston	108	19	0.4987	0.0430	49.0

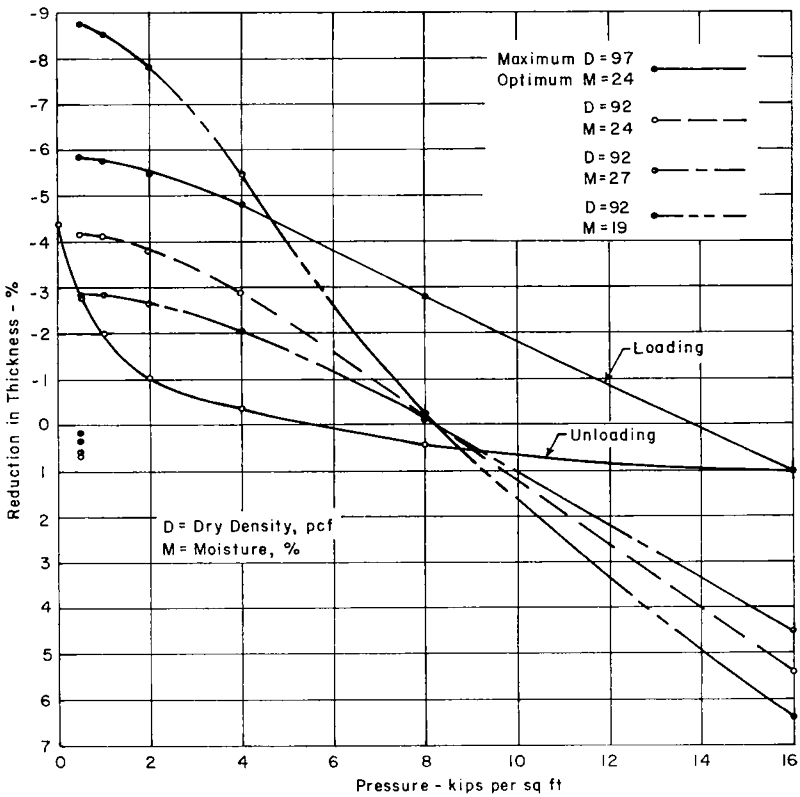

Figure 7. Consolidation stress-strain curves for Houston black clay.

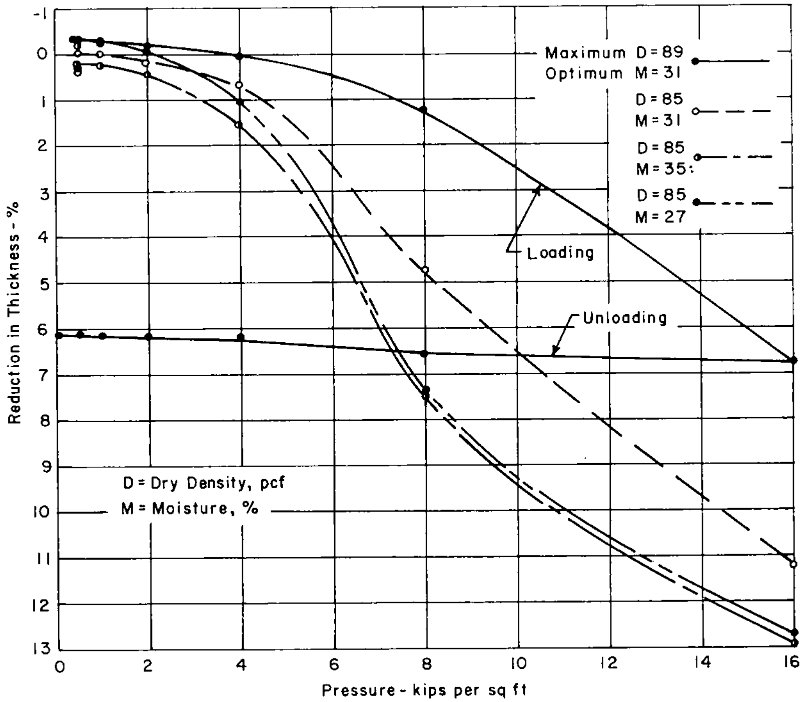

Figure 8. Consolidation stress-strain curves for Davidson clay loam.

First, test results prove that under heavier loads the soil is relatively less compressible when compacted to the maximum density at optimum moisture than under the other conditions. Obviously, based on the same moisture, the lower density makes the soil consolidate more, and different moisture contents have different effects on consolidation. At the initial state (in other words, before the soil is saturated) the compacted samples have very low compressibility under 0.5-ksf pressure, especially in the drier state.

The Houston soil is extremely sensitive in volume change due to the change of water content or loading. When it is compacted drier than optimum, or more dense, it swells greatly when it absorbs water, because there are greater internal forces between the soil particles and absorbing forces acting on the water molecules. A wide range of volume change (about 15 percent of the initial thickness) occurs in the clay that is 5 percent drier than optimum. This drier condition shows the worst performance; under lighter load the saturated clay expands continuously while being consolidated by the applied load. Sometimes the swelling is more than the consolidation. Under the maximum load, it is more compressible in this case. The wetter condition shows less consolidation of the three moistures. In this soil, a reduction of 5 percent in dry density increases the compression to about 5 times the result for the maximum density. The change of moisture content to 3 percent more and 5 percent less than optimum both affect the result less than 20 percent. In Figure 7, at a load of about 18 ksf, the curves of the same density and different moistures come very close together. This means

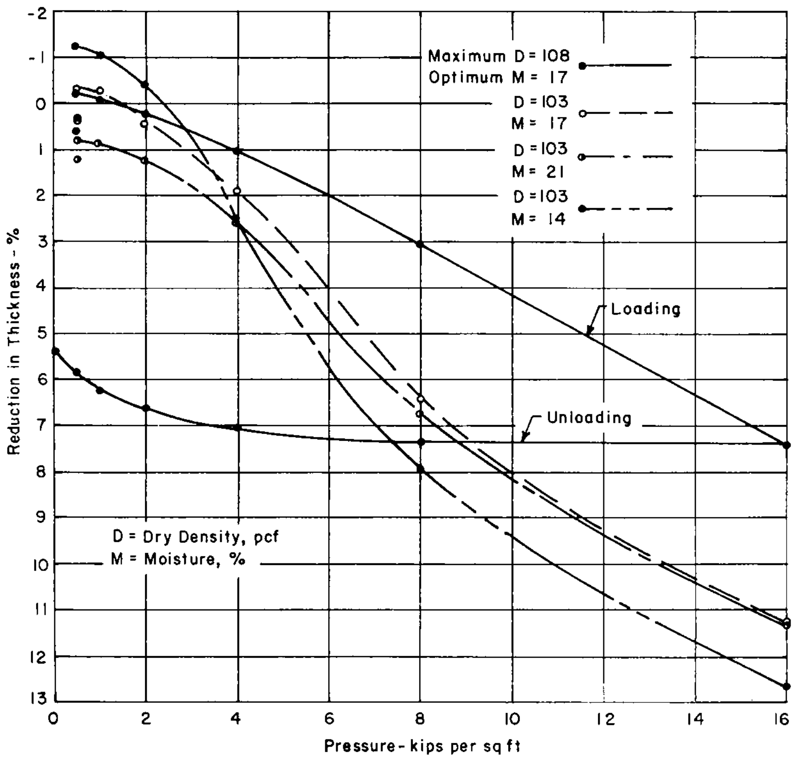

Figure 9. Consolidation stress-strain curves for Williams loam.

that the moisture does not greatly affect the over-all consolidation.

The Davidson soil has some physical characteristics similar to Houston, but has much less volume change. When it is quite wet it does not expand; it only expands when compacted to the dry or dense state initially. Under loads of more than 4 ksf, at the same density, the values of compression of the wetter state and the drier state are rather close, but the drier moisture is a little better. The optimum moisture is the best condition of the three.

Although the Unified Classification indicates that the Williams soil has medium compressibility, the consolidation test results show that this soil is highly compressible. It expands but little when it becomes saturated, especially in the wet sample. Under loadings of 8 and 16 ksf, the consolidation results are close for the samples at optimum and 4 percent more than optimum with the same density. The drier condition is the worst.

In Sharpsburg soil there is a wide range of volume change (about 17 percent) in the drier sample with a moisture 9 percent less than optimum. However, this soil has better performance and causes less trouble than Houston. At the same moisture, lower density only increases the compression about 1.7 times the value for the maximum density. At the same density different moistures have the same effects as Williams.

The Portneuf soil shows particular results in consolidation. Change of density from 100 percent to 95 per-

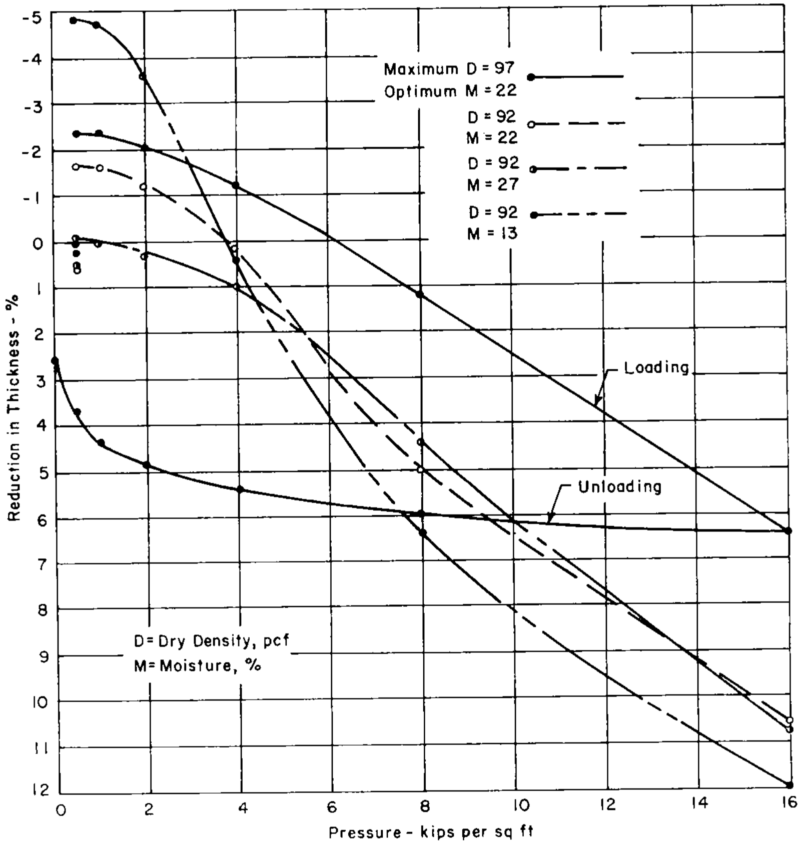

Figure 10. Consolidation stress-strain curves for Sharpsburg silt loam.

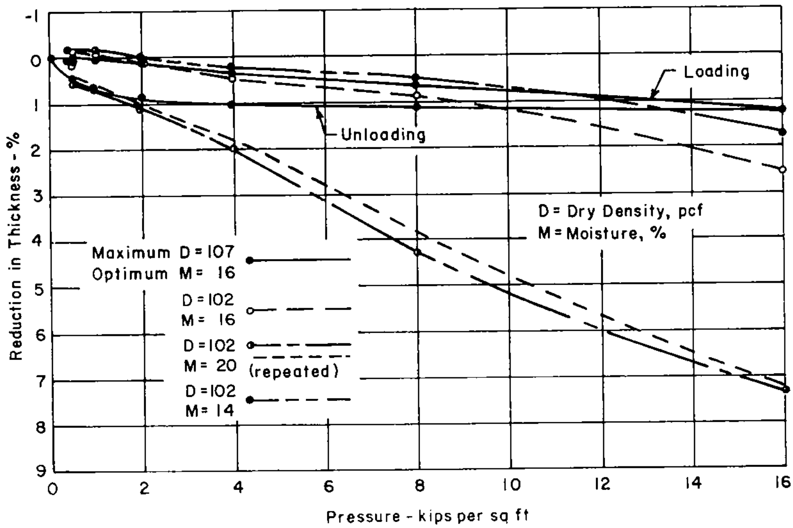

Figure 11. Consolidation stress-strain curves for Portneuf silt loam.

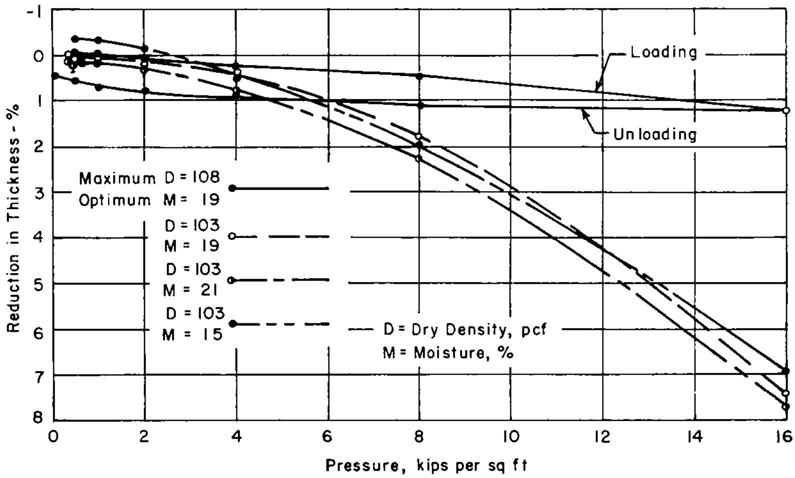

Figure 12. Consolidation stress-strain curves for Ruston loamy sand.

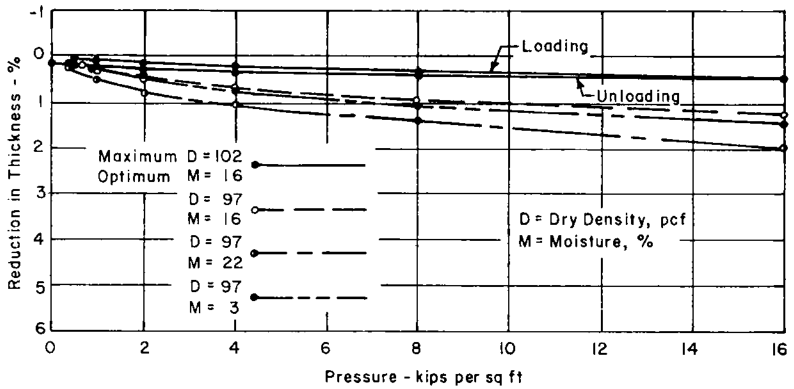

Figure 13. Consolidation stress-strain curves for Lakewood fine sand.

cent increases the reduction in thickness from 1.24 to 2.56 percent of initial thickness—about 2 times. Change of moisture increases the compression to about 3 times, by increasing moisture 4 percent more than optimum. Decreasing the moisture to 2 percent less than optimum gives entirely different results, about 70 percent of the value at optimum. Except for the wet sample, the stress-strain curves of the other three samples have similar shape. A repeated test shows the same phenomenon. From the classification of this soil, its compressibility is relatively low; the comparatively great amount of consolidation which occurs in the wetter state may be due to the structure of the soil and the effect of water, which fills the air voids in the soil and makes the material more compressible. The drier condition is the best. Special care is needed to treat this soil or soils of similar character when placed wetter than optimum.

The reduction in density has a

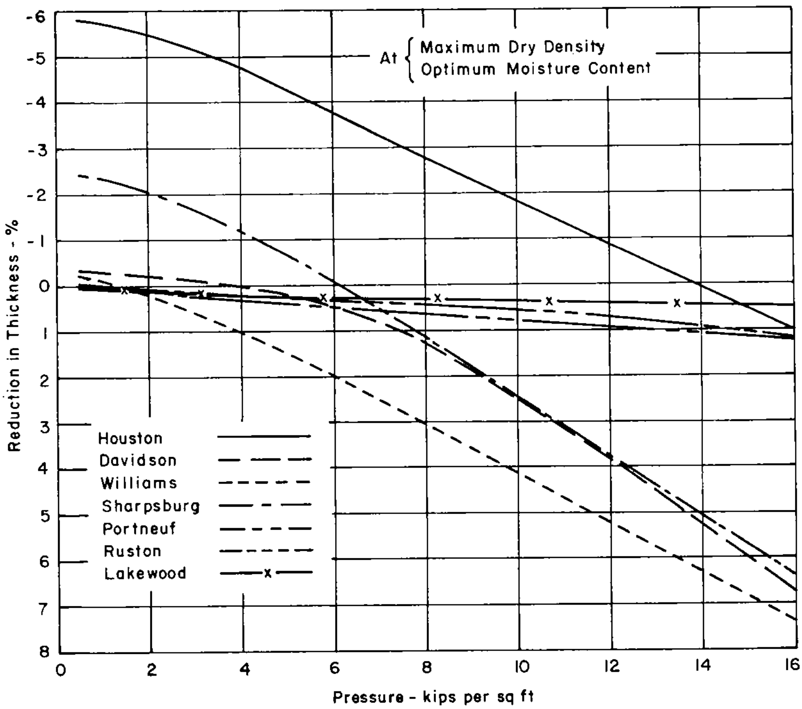

Figure 14. Consolidation stress-strain curves for seven soils.

great effect on the consolidation test result in such a soil as Ruston. At the maximum density the value for compression is small, but at 95 percent of the maximum density the value is approximately 6 times as great. This is the largest effect of density on consolidation amount for the seven soils. The variation of moisture has only a small effect. Test results show that the drier the sample the better the results under consolidation.

For a granular material in fine grain size such as Lakewood, there is almost no volume change when encountering water. This soil is relatively incompressible, particularly when under light pressure. The density gives an effect about 2.5 times when reducing the density 5 percent. The consolidation results for optimum moisture and very dry moisture of 3 percent at the same density are about the same amount under loads up to 2 ksf. Under heavier loads, the optimum condition shows up better. In this case, the wetter condition is worse than the other two.

Figure 14 compares the compression of the seven soils at maximum density and optimum moisture. The Houston, Williams, and Sharpsburg soils have about the same rate of strain at loadings up to 8 ksf. Houston has the highest elasticity, with Sharpsburg second. Under the heaviest load, Houston has as much consolidation as those silty and sandy soils, but as soon as the load is released this clay swells greatly. This elastic character makes more trouble when the applied loadings are light. The Davidson has less compressibility initially, and becomes more compressible when gradually loaded, the maximum rate of strain is at 8 to 16 ksf. Portneuf and Ruston have the same ultimate consolidation at the end of 16 ksf loading. Evidently, the Lakewood is the best of the seven soils in the concept of consolidation behavior of soil.

From the laboratory test results, which indicate the behavior of each soil under consolidation, it can be predicted that the soils of these seven types, or soils of similar character, will have the same or similar phenomena in the field when placed at the same conditions of density and moisture. Because the specimens were kept saturated after the first loading until the end of test, this is equivalent to the condition in the field when a soil layer is compacted to the specific dry density and moisture, and then becomes saturated from rain or other sources of water. The applied load for test equals the surcharge or the load of structures in the field. Therefore, the laboratory test is in accordance with field conditions.

RELATED STUDIES

The test results of this research can be compared with previous works (*4, 5*).

The U.S. Bureau of Reclamation, in Technical Memorandum 648, has reported the consolidation of fill materials compacted near optimum to about 100 percent density (AASHO Standard Method). The maximum settlements can be obtained from the expression

$$\text{Consolidation} = \frac{\text{Compressibility (Density) (Height)}^2}{2{,}000} \qquad (2)$$

using a compressibility of 0.003 per kip per sq ft.

With the known compressibilties of the seven soils, the maximum settlements due to various heights of the soil layers in the field can also be obtained by using the same method.

From 1- to 16-ksf loads the following compressibilities are calculated:

Soil Type	*Compressibility per kip per sq ft*
Houston	0.004
Davidson	0.004
Williams	0.005
Sharpsburg	0.006
Portneuf	0.001
Ruston	0.001
Lakewood	0.0004

The densities required at different depths under traffic are given in "Compaction Requirements for Soil" (*6*), and the range of densities for subgrade soils and base materials in construction has been suggested in HRB Bulletin 58 (*7*).

CONCLUSIONS

The time of consolidation is very short for the Lakewood under all pressures; a little longer for such silty soils as Portneuf, then increases with increasing percentage of clay. The Houston and Davidson take more time to consolidate. Generally, the time of consolidation is less for materials compacted to maximum density at optimum moisture and to a drier moisture than optimum under lighter loads.

The clayey materials (such as Houston, Davidson, Williams, and Sharpsburg) have a large volume change. The Houston expands greatly when saturated.

For cohesiveless materials (such as silty soils, sandy soils, and granular materials) the denser the better; but for clayey soils which have a high volume change this is not applicable and the density for this type of soil is not required to be very high.

For consolidation, based on the same moisture content lower density, of course, makes the soil consolidate more. This is applicable to all soil samples tested, but the amount of consolidation affected by density varies with the soil type. For instance, at 95 percent maximum density the thickness reduction is from 1.5 to 6 times the value obtained for the maximum density. Based on the same density, different moisture contents have different effects on consolidation, depending on the characteristics of the soil. For clayey soils (such as Houston, Williams, and Sharpsburg) the drier condition is the worst for the consolidation behavior. This is because the clay expands greatly when it absorbs water. On the other hand, for slightly plastic silty soils or sandy soils the wetter condition gives worse results because the water helps the densification of the soil in the period of applying load.

The test results show that density plays an important role in affecting the compression characteristics of the compacted soils. The amount of consolidation affected by moisture is not great except for the unusual case in the Portneuf silt loam. These results obtained from the seven selected samples can be used as a guide to investigate the consolidation behavior that might be expected in similar soils at the maximum dry intensity and optimum moisture, or in the neighborhood of this condition.

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