Triaxial Tests in Analysis of Flexible Pavements

CHESTER McDOWELL, Senior Soils Engineer,
Texas Highway Department

A previously published method of comparing strengths of soils, as measured by triaxial tests, to estimated wheel-load stresses is discussed with respect to subsequent revisions in testing procedure and methods of interpretation. In order to show how this method of pavement analysis correlates with service behavior of existing pavements, ten projects in south, central, and west Texas were investigated. The investigation included: service behavior, age, traffic loads, thickness of pavement layers, triaxial tests, soil constants and gradation for all subgrades, subbases and bases. From this study it appears that a correlation exists between "percent design" and life of pavements.

A report covering the development and use of triaxial tests for subgrade soils and flexible base materials was presented to the Highway Research Board by the author in 1946. In 1949, we submitted another report including a classification chart and a depth of pavement table which were published in Highway Research Board Bulletin 8-R. The classification chart has been revised once since then in 1952 so as to accommodate for the classification of cohesionless sands. The depth of pavement table was revised and presented in graphical form in 1951 to avoid having to distinguish between high and low modulus base materials.

● THE testing procedure used today for disturbed soils is still essentially the same as reported in 1946, except that the use of some newer and better testing machines have been adopted. For the benefit of those who are not familiar with the particular method of testing used, the following is a brief summary of the method. A more detailed procedure, THD-80, is included in the appendix.

1. A 200- to 300-lb. sample is air dried and separated into various ranges of particle sizes. Portions retained on the 2-inch screen are crushed or excluded.

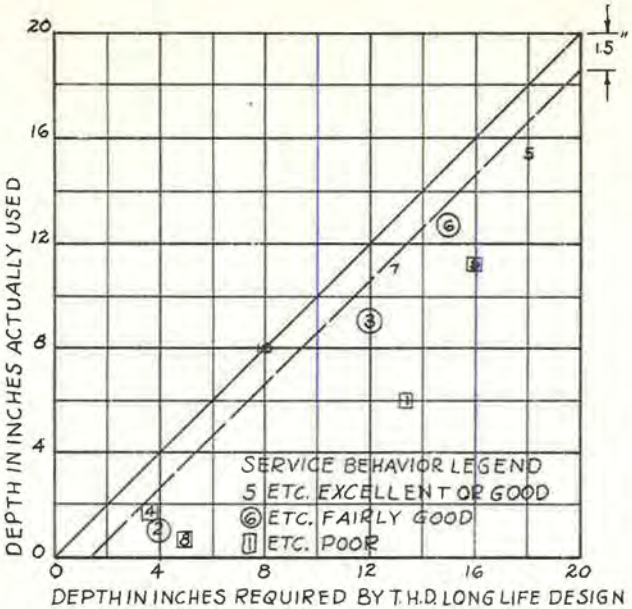
2. A moisture-density curve for a selected compactive effort is obtained by molding 6-inch-diameter by 8-inch-height specimens in four equal layers of 2-inch thickness each. The batch for each specimen consists of grain size components which have been recombined on the basis of the original gradation obtained in Step 1.

3. Six specimens, as nearly identical as possible, are compacted at optimum moisture content. All specimens are weighed, measured and extruded from the molds. Porous stones are placed on top and bottom.

4. After storing overnight, specimens consisting of materials that do not develop shrinkage cracks are partially dried by placing in an air-drying oven (forced draught at 140 F.) for a period of 8 hours. Upon removal, the specimens are allowed to stand overnight in the open laboratory. The specimens again are weighed. Usually, about two thirds to one half of the molding moisture is removed. Materials that tend to develop shrinkage cracks are not dried.

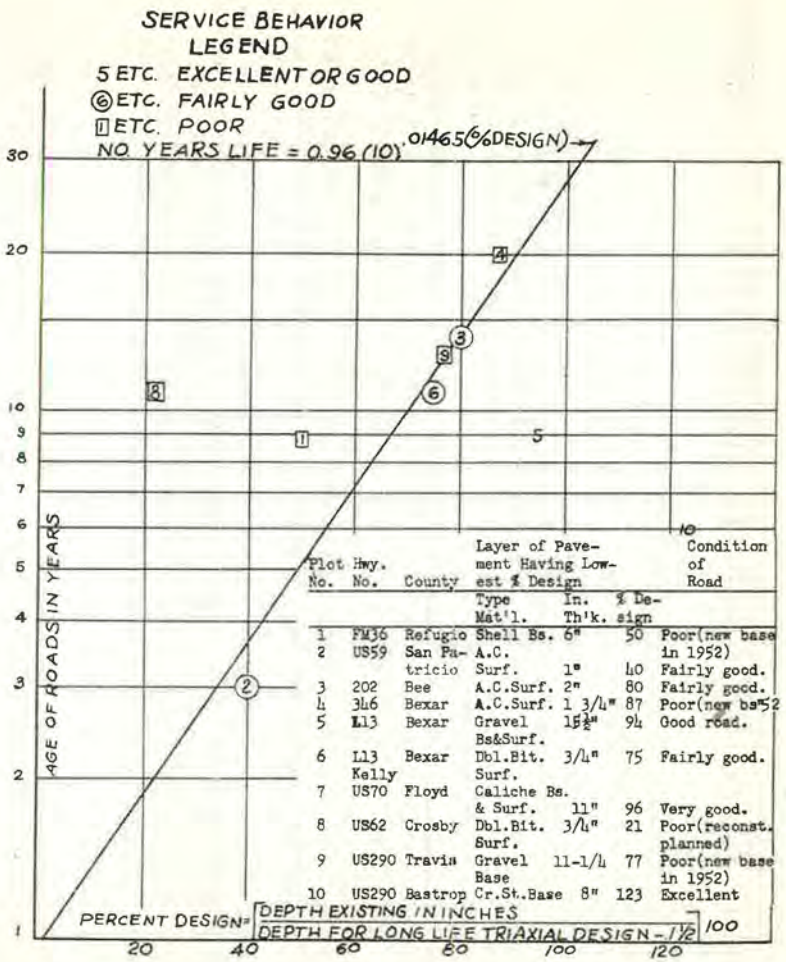
5. The axial cells, deflated by vacuum, are placed on the specimens. A suitable vertical surcharge (about 0.33 to 1.00 psi. for most subgrades) is placed on the top stone. The specimens are then placed in pans of water so that the water level is ½ inch below the bottom of the specimen itself. This assembly is then placed on the storage rack in the moisture room and connected with the constant pressure air manifold. The usual lateral pressure is 1 psi. The specimens are permitted to absorb water by capillarity until equilibrium is attained.

6. Each specimen is tested in compression at a constant lateral pressure. The six identical specimens are usually tested at lateral pressures of 0, 3, 5, 10, 15 and 20 psi., respectively. This pressure is applied by means of the cells, supplied by an auxiliary air tank. The rate of strain is 0.15 inch per minute. Simultaneous readings of load and defor-



Plot No.	Highway No.	County	Layer of Pavement Requiring Thickest Cover: Type Mat'l.	Inches Thickness: Existing	Inches Thickness: For Design	Condition of Road
1	FM-36	Refugio	Shell Base	6	13-1/2	Poor (new base in '52)
2	US-59	San Patricio	A.C. Surface	1	4	Fairly good.
3	202	Bee	Caliche Base	9	12	Fairly good.
4	346	Bexar	A.C. Surface	1-3/4	3-1/2	Poor (new base in '52)
5	Loop 13	Bexar	Gravel Base & Surface	15-1/2	18	Good road.
6	Loop 13 Kelly	Bexar	Dbl. Bit. Surf.	12-3/4	15	Fairly good.
7	US-70	Floyd	Caliche Base & Surface	11	13	Very good.
8	US-62	Crosby	Dbl. Bit.	3/4	5	Poor (reconstruction planned.)
9	US-290	Travis	Gravel	11-1/4	16	Poor (new base in '52)
10	US-290	Bastrop	Cr. St. Base	8	8	Excellent

Figure I. Relation of actual depths used to depths required by T.H.D. triaxial test for layers of pavement requiring greatest thickness of coverage.



Plot No.	Hwy. No.	County	Layer of Pavement Having Lowest % Design: Type Mat'l.	In. Th'k.	% Design	Condition of Road
1	FM36	Refugio	Shell Bs.	6"	50	Poor(new base in 1952)
2	US59	San Patricio	A.C. Surf.	1"	40	Fairly good.
3	202	Bee	A.C.Surf.	2"	80	Fairly good.
4	346	Bexar	A.C.Surf.	1 3/4"	87	Poor(new ba"52
5	L13	Bexar	Gravel Bs&Surf.	15½"	94	Good road.
6	L13 Kelly	Bexar	Dbl.Bit. Surf.	3/4"	75	Fairly good.
7	US70	Floyd	Caliche Bs. & Surf.	11"	96	Very good.
8	US62	Crosby	Dbl.Bit. Surf.	3/4"	21	Poor(reconst. planned)
9	US290	Travis	Gravel Base	11-1/4	77	Poor(new base in 1952)
10	US290	Bastrop	Cr.St.Base	8"	123	Excellent

Figure II. Relation of pavement life to percent design*.

TABLE I

Highway No.	County	Road Age Yrs.	Wheel Load* (in Pounds)	Pavement Layer Thickness (Inches)	Triaxial Strength Class	No. Inches Coverage Required by Tests**	Percent Design***	Service Behavior of Road
FM-136	Refugio	9	6,100	½" single asph. surf.				New base placed over old base in 1952
				5½" shell	1	1	****	
				Clay Subg.	4.9	13½	50	
US-59	San Patricio	3	12,500	1" A. C. surfacing				Fairly good.
				10" caliche	3.1	4	40	
				Subgrade	3.4	7	200	
202	Bee	14	5,000	2" A. C. Surfacing				Fairly good.
				7" caliche	3.3	4	80	
				Subgrade	4.8	12	86	
346	Bexar	20	4,500	1¾" A. C. surfacing				Poor; new base placed over old base in 1952
				13" gravel	3.1	3½	87	
				Subgrade	3.1	3½	737	
Loop 13 Lackland Air bs.	Bexar	9	8,200	2½" A. C. surfacing				Good.
				13" gravel	2.8	2¾	200	
				Subgrade	5.2	18	94	
Loop 13 Kelly Overpass	Bexar		8,100	¾" dbl. bit. surf.				Fairly good.
				12" gravel	2.7	2½	75	
				Subgrade	4.7	15	94	
US-70	Floyd	14	6,700	2" triple bit. surf.				Excellent
				9" caliche	3.1	3½	100	
				Subgrade	4.6	13	96	
US-62	Crosby	11	7,900	¾" dbl. bit. surf.				Reconstruction planned.
				7" caliche	3.4	5	21	
				Subgrade	4.4	12	74	
US-290	Travis	13	8,400	1¼" triple bit. surf.				Reconstructed after 13 yrs. service.
				10" gravel	3.0	3	83	
				Subgrade	4.9	16	77	
US-290	Bastrop	6	16,000	¼" single bit. surf.				Excellent
				7¾" cr. stone base	1	1	****	
				Subgrade	3.4	8	123	

*Estimated average of 10 heaviest wheel loads per av. day during years road has been in service. Data furnished by THD Highway Planning Survey Division.
**Triaxial tests for long-life design.
***Percent Design = (Depth existing divided by depth required by tests minus 1½ in.) 100
****Percent design is very high but cannot be determined from the formula.

mation are taken at intervals of 0.01 inch of deformation. Loading continues until the specimen fails.

7. After the completion of the compression test, the entire specimen is dried at 110 C. On the basis of the total dry weight, extra data as to density, moisture content, moisture absorption, etc., may be calculated.

8. From the principal stresses at the instant of failure, Mohr's diagram of stress is constructed.

9. A portion of the Mohr envelope is transferred to a classification chart and the strength class of the material is determined to the nearest tenth.

10. The depth of coverage in inches for

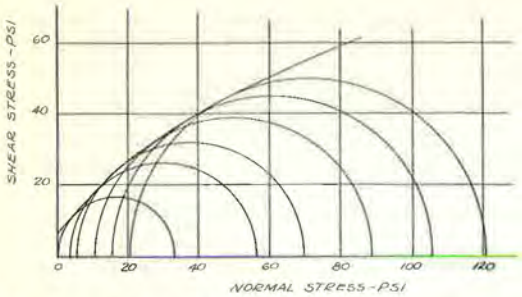


Figure 1. Mohr's Diagram, Lab. No. 50-72-R San Patricio County US 59.

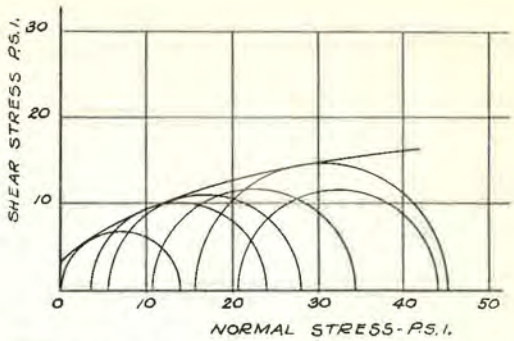


Figure 4. Mohr's Diagram, Lab. No. 50-81-R Bexar County, Loop 13, Kelly Field Overpass.

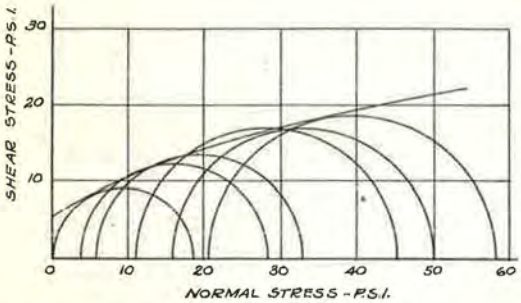


Figure 2. Mohr's Diagram, Lab. No. 50-93-R Crosby County, US 62.

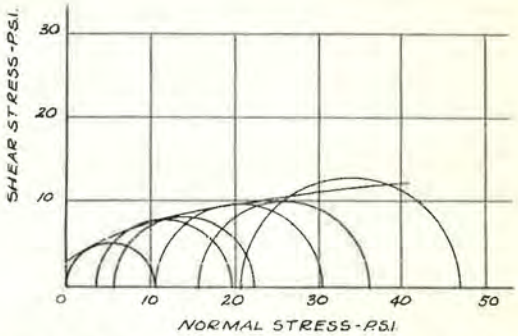


Figure 5. Mohr's Diagram, Lab. No. 50-77-R Refugio County F.M. 136.

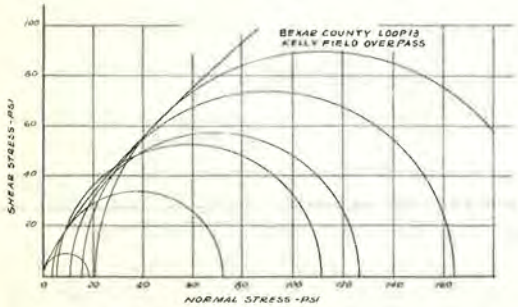


Figure 3. Mohr's Diagram, Lab. No. 50-80-R.

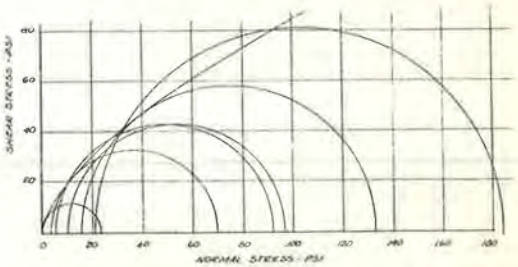


Figure 6. Mohr's Diagram, Lab. No. 50-78-R Bexar County, Loop 13, Lackland Air Force Base.

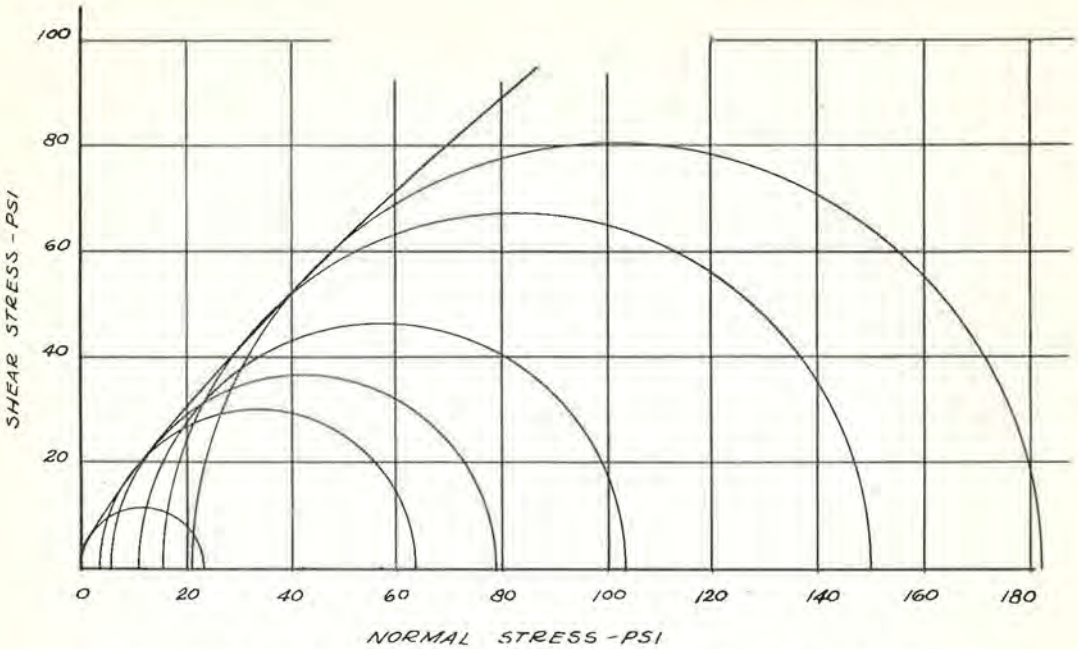


Figure 7. Mohr's Diagram, Lab.No.50-82-R, Bexar County St. Hwy.346.

a given wheel load is obtained by entering these data on a design chart.

The entire procedure when reduced to its simplest terms consists of comparing strength to stress for all layers of flexible pavement. The strength of the material is determined from carefully controlled triaxial tests and compared to a given wheel-load-stress condition by plotting the shear strength envelope on the above-mentioned classification chart. This chart has been derived from experience and

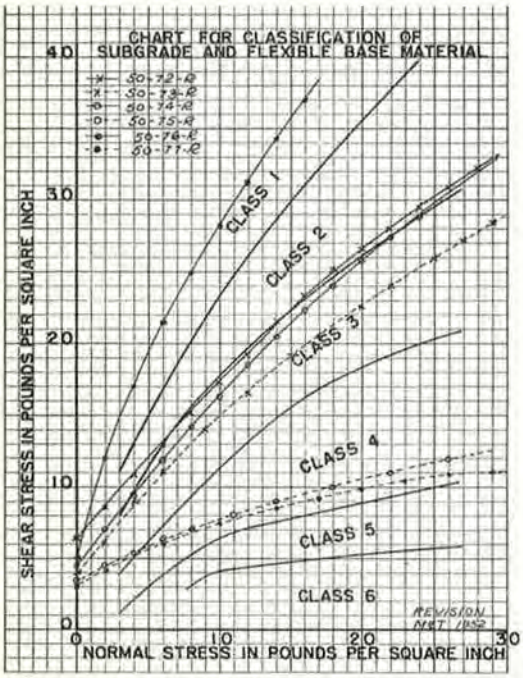


Figure 8.

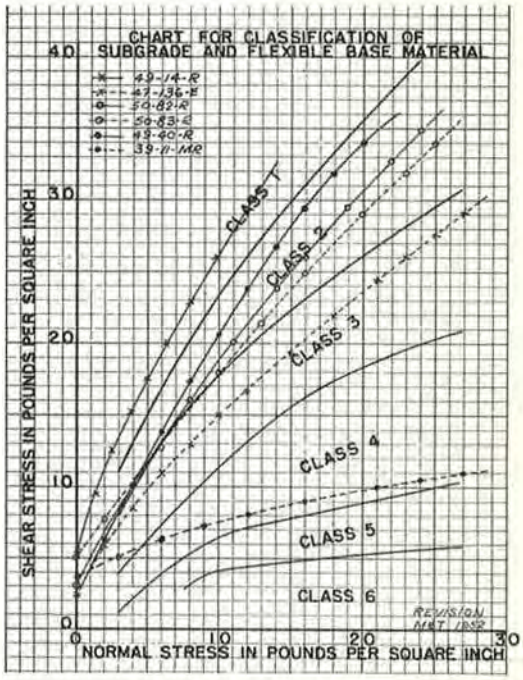


Figure 9.

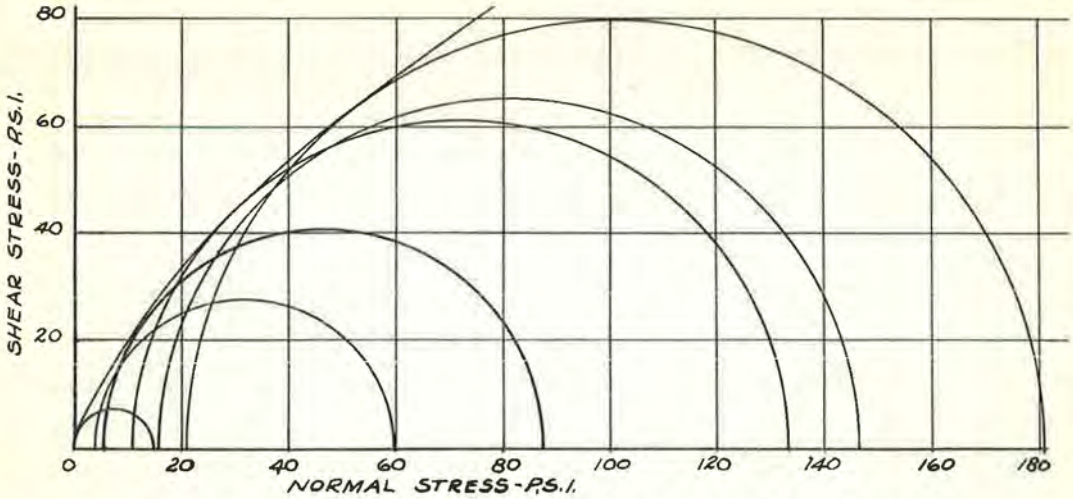


Figure 10. Mohr's Diagram, Lab.No.49-40-R, Travis County US 290.

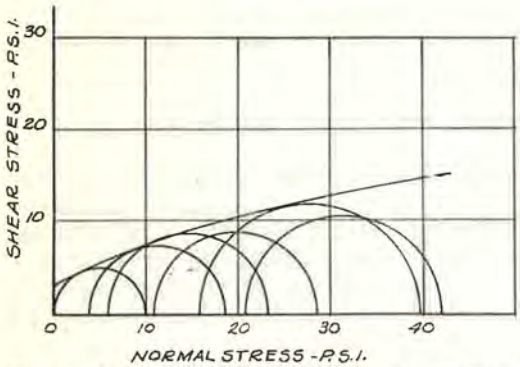


Figure 11. Mohr's Diagram, Lab. No. 50-75-R Bee County St. Hwy. 202.

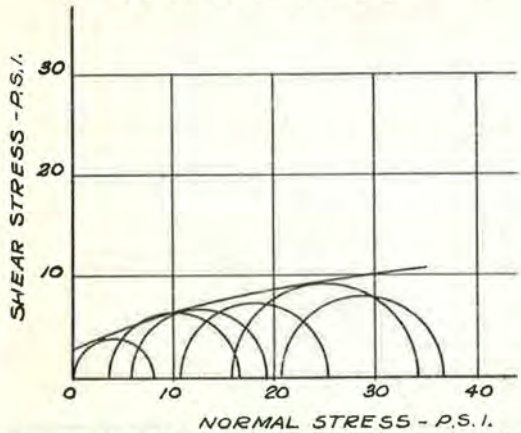


Figure 12. Mohr's Diagram, Lab. No. 50-84-R Bexar County, Loop 13, Lackland Air Force Base.

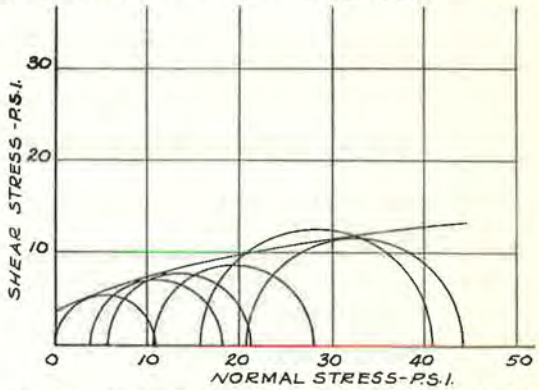


Figure 13. Mohr's Diagram, Lab. No.39-11-MR Travis County, US 290.

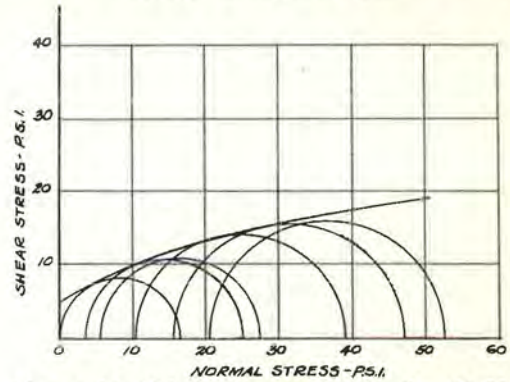


Figure 14. Mohr's Diagram, Lab. No. 50-91-R Floyd County, US 70.

certain theoretical concepts. The stress conditions for a variety of wheel loads, based upon constant tire pressures, may be analyzed by use of the pavement-analysis chart mentioned above. The primary purpose of this report is to show how well this method of analysis correlates with actual service behavior of flexible pavements. In order to do this, a thorough

analysis of pavements, including service behavior, age, weight and volume of traffic, thicknesses of pavement layers, triaxial tests, soil constants and gradation on subgrades, subbases and bases, was made on ten projects located in south, central, and west Texas. Samples weighing 200 to 300 lb. each were taken from each layer of subgrade, subbase or base after cutting large holes in existing pavements. At this time thicknesses of all layers of pavements were measured. The age of the pavement and an evaluation of its service behavior were obtained from

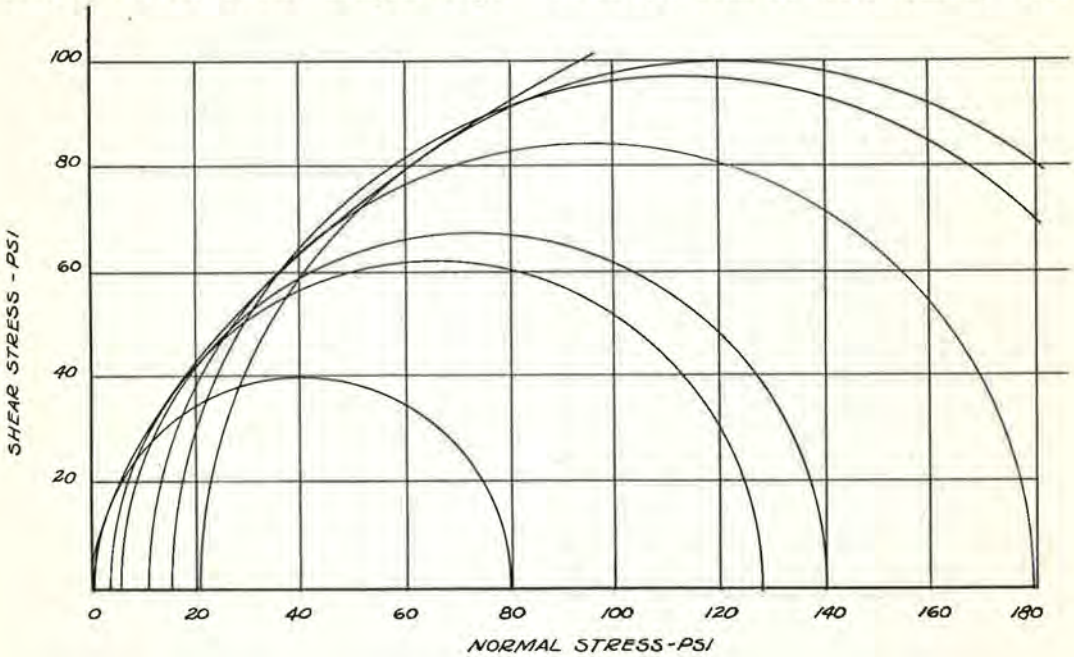


Figure 15. Mohr's Diagram, Lab. No. 50-76-R, Refugio County F.M. 136.

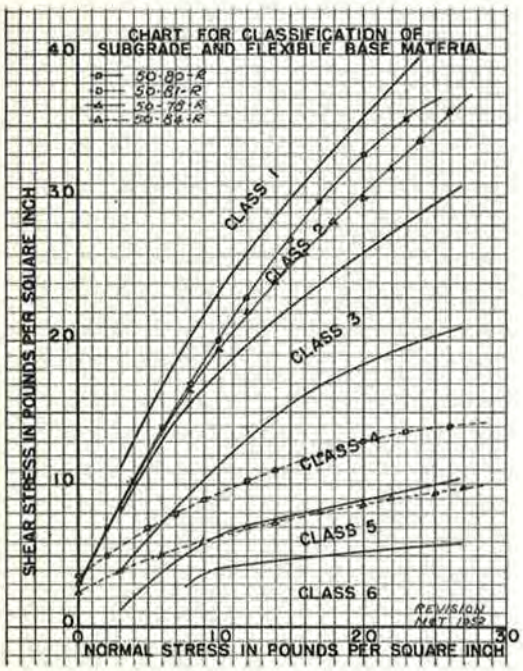


Figure 16.

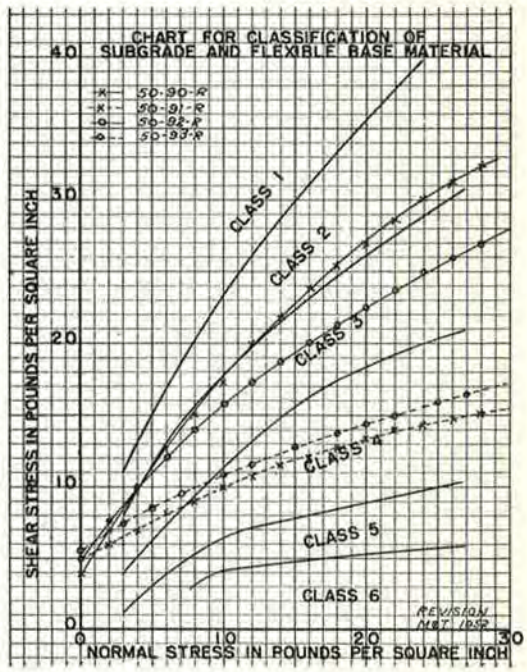


Figure 17.

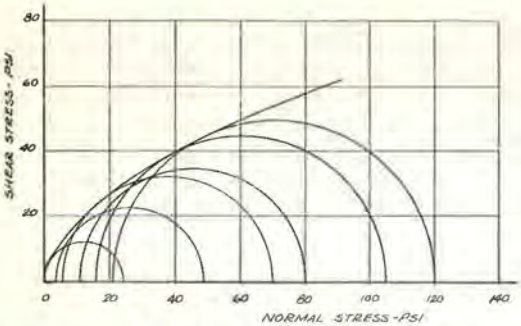


Figure 18. Mohr's Diagram, Lab. No. 50-90-R Floyd County, US 70.

state highway district and Bureau of Public Roads' personnel. Soil constants and gradation are shown on form sheets 476-A (see appendix). Results of triaxial tests for all soils tested are plotted in the form of Mohr diagrams as Figures 1-7, 10-15, and 18-24. Strength classifications for all soils tested are shown in Figures 8, 9, 16, and 17. Pertinent data pertaining to compaction, curing, absorption, and testing of all specimens are shown in Tables 1 to 20.

To study these projects objectively, estimates of the average of the ten-heaviest wheel loads per average day during the life of these pavements were obtained. Since these are averages over a period of years, it may be noted that many of the old projects showed much-lower wheel-load averages than newer projects.

Wheel-load data and test results are shown in Table I. Data shown in this tabulation, for layers of pavements needing greatest increase in thickness as judged by triaxial design, are plotted in Figure I, so as to show the relation of existing depths for design thicknesses. Figure I indicates that good long-life pavements may be approximately 1½ inches thinner than required by our design procedure; therefore, in construction of new projects we often reserve an inch or two of surfacing for future application. It may also be noted that Points 2 and 4 are close together on this chart, although one is from a fairly good road the other was from a poor road, the difference being that the poor road is 20 years old and the fairly good road is only 3 years old. Figure II shows the relation of road age to "percent design" expressed as 100 (ratio of existing depth to depth required by triaxial tests minus 1½ in.). This chart separates Points 2 and 4 more nearly as should be.

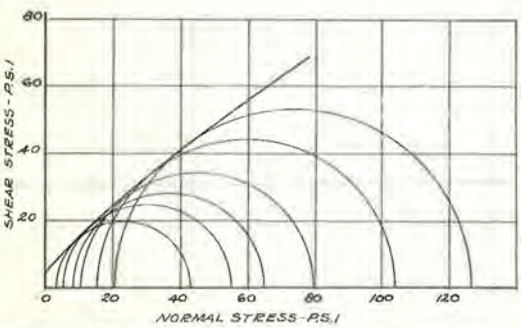


Figure 19. Mohr's Diagram, Lab. No. 47-136-E Bastrop County, US 290.

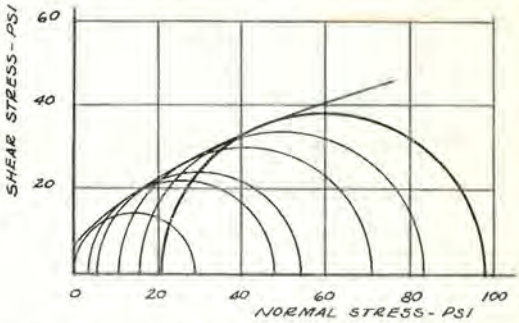


Figure 20. Mohr's Diagram, Lab. No. 50-92-R Crosby County, US 62.

In fact, all points tend to be arranged so that the line represented by the expression, "No. years life = . . . ," divides points for road failures on the left from points for good and excellent roads on the right of the line. The results shown are limited; however, for the time being they will help explain why some underdesigned pavements are not failing rapidly. It is also believed that these relations will help designers select design thicknesses in keeping with engineering and economical needs, whether for a short-life road requiring relocation soon, for stage construction, or for long-life urban sec-

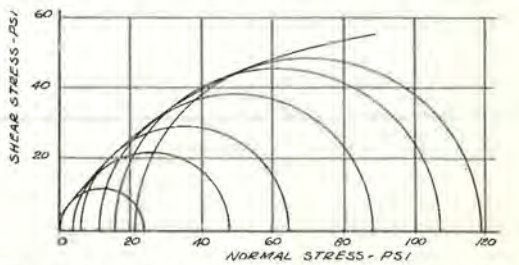


Figure 21. Mohr's Diagram, Lab. No. 50-74-R Bee County St. Hwy. 202.

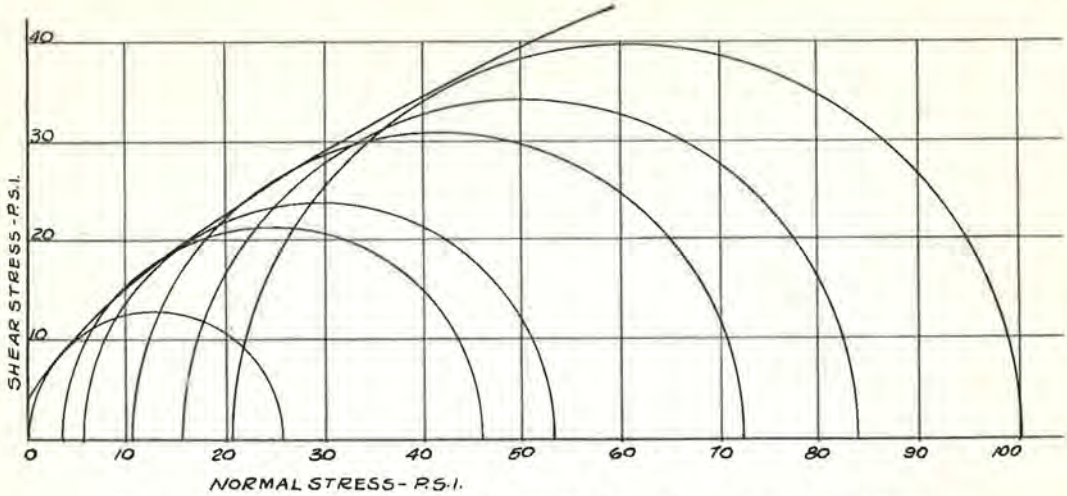


Figure 22. Mohr's Diagram, Lab. No. 50-73-R San Patricio County US 59.

tions. It is doubtful that the term "percent design" is of much value in estimating the life of bituminous surfacings which are less than 1½ inches thick, because the triaxial method does not measure the properties of asphalts. Since the amount of maintenance required for roads is somewhat dependent upon skill and timing of operations, it is by no means certain that projects having similar percentages of design will require the same amounts of maintenance. General observation of some of these projects throughout their life bears out this statement.

For reconstruction of the above roads it is suggested that design loads should be increased considerably above those found to exist in the past because the weight of traffic in the future cannot usually be expected to be as light as it has been in the past. Planning Survey Divisions can be of much assistance in furnishing wheel load data for design. It is suggested that each layer in the entire pavement system be rechecked for percent design when proposing the application of new layers for reconstruction.

When designing for construction of new projects, the following steps are recommended:

1. Use USDA county soil maps and geological survey data to form a soils area concept or at least a soils reconnaissance before sampling for triaxial tests. If this is done the number of subgrade soil samples required per mile may be as low as two or three, and the data may be applicable to other areas

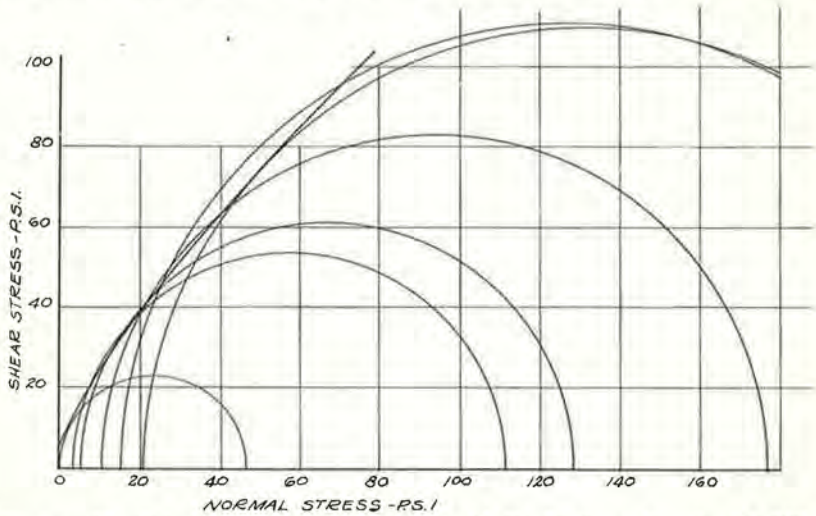


Figure 23. Mohr's Diagram, Lab. No. 49-14-R, Bastrop County US 290.

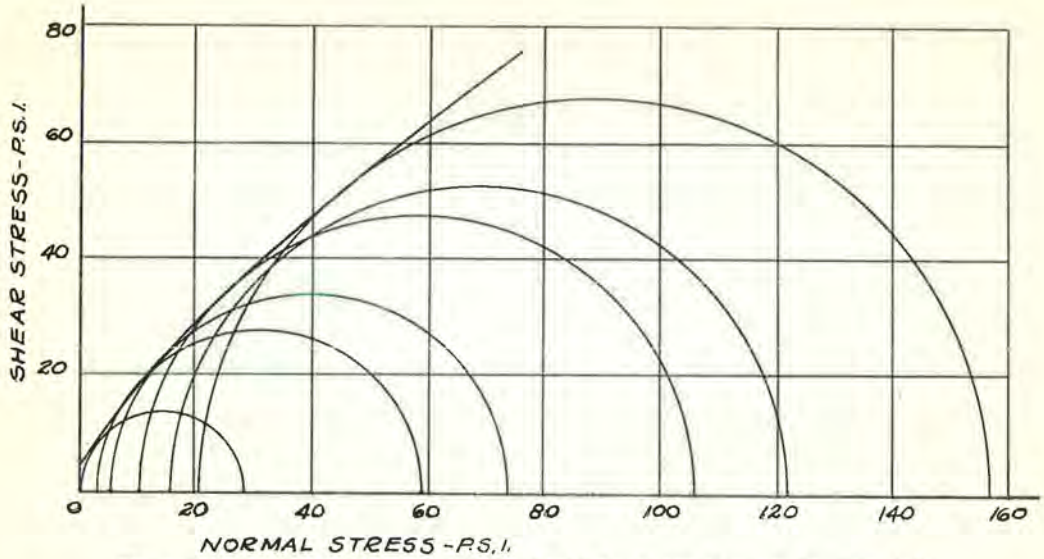


Figure 24. Mohr's Diagram, Lab.No. 50-83-R, Bexar County St. Hwy. 346.

shown by the map to be from a similar soil series and to have similar physical constants.

2. Selection of percent design depends upon the life of the road desired, the ease with which new layers of base or surfacing can be added in the future, and certain economical considerations.

3. It should be realized that designing for strength alone does not prevent the occurrence of detrimental shrinkage cracks. To avoid these it is suggested that granular layers or asphalt membranes be extended as far outside the edges of pavement as is economically feasible. This type of construction is essential only in high volume change areas or where the soil forms extensive shrinkage cracks.

4. In order to be assured of securing strengths of subgrades and pavement layers comparable to those obtained in testing, a method of compaction control is recommended. The method is fully described in a separate paper at this meeting by the author, entitled: "Selection of Densities for Subgrades and Flexible Base Materials."

CONCLUSIONS

1. Since the data obtained from triaxial tests made it possible to correlate percent design with life of pavements, it appears that triaxial methods can be used successfully to analyze most highway flexible pavement problems. In addition to estimating overall thicknesses on subgrades, the method also determines the quality and density requirements of subbase and flexible base materials, the latter being equally, if not more, important than overall thickness because good pavements are a prerequisite to proper thickness evaluations. The term "percent design" appears to be a basic expression and is necessary in order to have a good understanding of flexible-pavement design.

2. The simplicity and workability of the method are attested to by the fact that approximately half of the district offices either have been or are being equipped for triaxial testing. This program has been carried out voluntarily by the Districts, and is not mandatory.

ACKNOWLEDGEMENT

The writer is indebted to many who have contributed, encouraged or assisted in the development of triaxial testing for use in the design of pavements. A few of these people or organizations have been mentioned in the text; however, it should be mentioned that the work of the members of the Soils Section and other members of the Materials and Tests Division of the Texas Highway Department has been a major factor in making this report possible. The author is also indebted for assistance received from personnel of the Ft. Worth office of Bureau of Public Roads and the Road Design and Highway-Planning Survey divisions of the Texas Highway Department.

TMD-80

Table No. 1

Lab. No. 50-72-R County San Patricio Hwy. US 59 Project

Material Caliche Base Identification

Description 10 inches of caliche

Opt. Moist. 14.8 Opt. Dry Density 111.1 at Comp. Effort 13.26 ft.lb./cu.in.

Molding Data			Curing Data Moist. Cont.				Stress-Strain Relations					
							Straight Portion				Ultimate	
							From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. Lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
4	14.8	114.1	9.8	16.5	Small	0.0	14.0	0.80	26	1.3	33.3	1.91
5	14.9	112.9	9.7	17.2	*	3.6	21	0.9	38	1.5	56.2	2.77
6	15.0	113.5	9.8	17.0	*	5.6	19	0.6	45.5	1.5	69.4	3.93
7	15.1	113.2	9.6	17.2	*	10.6	30	0.9	54	1.55	88.4	4.81
8	15.0	113.0	9.8	17.3	*	15.6	38	0.9	67	1.55	105.1	4.66
12	14.0	112.9	9.4	17.7	*	20.6	45	0.9	85	1.6	120.3	4.52

Remarks

TMD-80

Table No. 2

Lab. No. 50-73-R County Hwy. US 59 Project

Material Subgrade Soil Identification

Description

Opt. Moist. 11.6 Opt. Dry Density 118.7 at Comp. Effort 13.26 ft.lb./cu.in.

Molding Data			Curing Data Moist. Cont.				Stress-Strain Relations					
							Straight Portion				Ultimate	
							From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. Lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	Stress	% Strain
5	11.3	118.8	9.8	14.0	Small	0	11.5	0.60	18.0	1.25	25.9	2.5
6	11.6	118.6	10.1	14.0	*	3.6	14.0	0.50	26.0	1.40	46.0	5.0
4	11.9	118.5	9.6	13.9	*	5.6	18.5	0.50	26.0	0.90	53.4	5.0
8	11.7	118.7	10.1	13.8	*	10.6	18.0	0.40	39.0	1.10	72.1	5.9
7	11.7	118.8	10.1	13.9	*	15.6	18.0	0.40	50.0	1.50	83.9	7.4
9	11.7	119.0	10.3	13.8	*	20.6	26.0	0.50	54.0	1.40	100.1	7.1

Remarks

TMD-80

Table No. 3

Lab. No. 50-74-R County Bee Hwy. 202 Project

Material Caliche Base Identification

Description 7" of Caliche Base

Opt. Moist. 17.7 Opt. Dry Density 107.8 at Comp. Effort 13.26 ft.lb./cu.in.

Molding Data			Curing Data Moist. Cont.				Stress-Strain Relations					
							Straight Portion				Ultimate	
							From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. Lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
3	17.6	107.9	17.6	21.5	Small	0.0	14.0	0.8	21.0	1.4	23.3	1.78
9	17.6	108.1	18.3	21.5	*	3.7	22	1.2	38	2.2	47.2	3.30
6	17.7	108.1	17.8	21.6	*	5.7	28	1.15	46	2.1	64.4	4.32
5	17.8	108.1	17.7	21.7	*	10.7	26	0.75	52	1.9	87.9	5.98
8	17.8	107.2	17.7	22.0	*	15.7	30	0.7	56	1.7	106.3	6.06
7	17.8	107.1	17.7	22.1	*	20.7	31	0.6	60	1.65	119.7	7.56

Remarks

TMD-80

Table No. 4

Lab. No. 50-75-R County Hwy. 202 Project

Material Subgrade Soil Identification

Description

Opt. Moist. 16.8 Opt. Dry Density 107.0 at Comp. Effort 6.63 ft.lb./cu.in.

Molding Data			Curing Data Moist. Cont.				Stress-Strain Relations					
							Straight Portion				Ultimate	
							From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. Lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
6	16.8	106.1	16.0	20.4	1.8	0	2.5	0.10	5.5	0.30	9.8	1.7
7	16.4	107.1	15.3	20.1	3.0	3.6	5.0	0.15	9.5	0.30	18.5	2.3
2	17.9	106.4	15.6	20.1	1.5	5.6	6.0	0.10	12.5	0.40	27.9	3.0
5	16.6	107.3	15.8	20.0	2.8	10.6	8.0	0.15	14.5	0.40	28.4	2.8
10	16.6	107.4	16.1	19.8	2.2	15.6	12.5	0.15	20.0	0.40	39.4	3.5
9	16.7	107.4	16.0	20.0	3.0	20.6	14.5	0.10	21.0	0.40	41.7	3.9

Remarks

THD-80

Table No. 5

Lab. No. 50-76-R County Refugio Hwy. FM-136 Project

Material Shell Identification

Description 5-1/2 inches of shell base

Opt. Moist. 12.5 Opt. Dry Density 119.6 at Comp. Effort 13.26 ft.lb./cu.ft.

Molding Data		Curing Data Moist. Cont.				Stress-Strain Relations					
						Straight Portion				Ultimate	
						From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
9	12.4	119.5	5.0	10.6	Small	0.0	22	1.05	50	2.25	79.9	5.25
11	12.4	119.5	4.7	10.5	*	3.6	30	0.9	83	2.75	127.3	6.31
12	12.5	119.4	5.1	10.9	*	5.6	42	1.2	83	2.40	139.7	6.18
7	12.3	119.7	5.2	10.7	*	10.6	43	0.8	92	1.85	187.8	7.51
8	12.4	119.6	5.1	10.7	*	15.6	28	0.4	83	1.60	208.5	7.75
10	12.7	119.6	5.2	10.7	*	20.6	20	0.2	85	1.40	220.0	7.17

Remarks

THD-80

Table No. 7

Lab. No. 50-78-R County Bexar Hwy. Loop 13 Project

Material Gravel Identification

Description 13* Gravel Base near Lackland Air Base

Opt. Moist. 6.8 Opt. Dry Density 135.4 at Comp. Effort 13.26 ft.lb./cu.ft.

Molding Data		Curing Data Moist. Cont.				Stress-Strain Relations					
						Straight Portion				Ultimate	
						From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
4	6.8	135.4	4.0	8.2	Small	0.0	0.0	0.0	9.0	0.5	22.6	2.22
6	6.8	135.4	3.9	7.9	*	3.6	15.0	0.5	28.0	0.9	69.8	3.13
1	6.6	135.8	3.7	8.1	*	5.6	23.0	0.6	46.0	1.05	91.3	4.63
4	6.8	135.4	3.9	8.0	*	10.6	28.0	0.6	67.0	1.45	96.2	4.13
7	6.7	136.4	3.9	7.7	*	15.6	39.0	0.75	68.0	1.25	132.5	7.06
5	6.8	136.1	3.9	7.8	*	20.6	40.0	0.55	100.0	1.35	183.8	4.92

Remarks

THD-80

Table No. 6

Lab. No. 50-77-R County Hwy. FM-136 Project

Material Subgrade Soil Identification

Description

Opt. Moist. 17.9 Opt. Dry Density 104.7 at Comp. Effort 6.63 ft.lb./cu.ft.

Molding Data		Curing Data Moist. Cont.				Stress-Strain Relations					
						Straight Portion				Ultimate	
						From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
2	17.9	104.1	15.4	21.2	1.8	0	0.0	0.0	6.0	0.30	10.5	1.2
6	17.9	104.6	18.3	21.3	2.7	3.6	1.0	0.0	11.0	0.40	19.7	2.6
4	18.0	104.6	15.8	21.4	2.4	5.6	2 0	0.0	12.0	0.40	22.3	2.8
7	17.7	104.9	17.4	21.7	3.6	10.6	6.5	0.1	19.0	0.65	30.3	3.1
5	17.8	105.0	18.0	21.3	2.5	15.6	7.0	0.0	22.5	0.60	35.9	2.7
8	18.0	105.2	17.8	21.4	3.0	20.6	10.5	0.0	34.0	0.75	46.9	2.8

Remarks

THD-80

Table No. 8

Lab. No. 50-84-R County Hwy. Loop 13 Project

Material Subgrade Soil Identification

Description Subgrade near Lackland Air Base

Opt. Moist. 33.4 Opt. Dry Density 80.7 at Comp. Effort 4.0 ft.lb./cu.ft.

Molding Data		Curing Data Moist. Cont.				Stress-Strain Relations					
						Straight Portion				Ultimate	
						From		To			
Spec. No.	% Moist. Dry Weight	Dry Den. lbs./Cu.Ft.	% After Dry.	% Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain	PSI Unit Stress	% Strain
2	33.9	79.7	36.6	40.5	3.18	0	0.5	0.0	5.5	0.40	7.9	1.02
4	33.3	80.0	38.0	40.5	4.69	3.6	1.5	0.0	9.5	0.35	16.6	1.78
7	33.3	80.9	36.1	40.4	5.24	5.6	2.0	0.0	12.5	0.50	18.9	1.91
6	33.2	81.1	36.0	39.5	5.87	10.6	6.0	0.15	15.0	0.65	25.1	2.54
5	33.4	81.2	35.3	40.2	5.23	15.6	7.0	0.0	23.0	0.80	33.9	3.84
8	33.5	81.2	36.4	40.5	5.30	20.6	13.5	0.15	28 0	1.00	36.4	7.82

Remarks

TRD-80

Table No. 9

Lab. No. 50-80-R County Bexar Hwy. Loop 13 Project

Material 12" Gravel Base Identification

Description Near Kelly Field Overpass

Opt. Moist. 6.2 Opt. Dry Density 139.4 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
9	6.2	139.1	3.4	6.4	Small	0.0	0.0	0.0	11.0	0.9	18.5	2.07
10	6.3	138.6	3.6	6.8	*	3.6	22.0	0.9	47.0	1.65	72.2	4.25
11	6.2	139.4	3.1	6.4	*	5.6	26.0	0.9	66.0	2.1	110.9	5.97
12	6.1	139.5	3.3	6.2	*	10.6	27.0	0.65	74.0	1.9	125.6	5.84
13	6.1	139.0	3.2	6.3	*	15.6	28.0	0.55	100.0	2.30	163.7	6.32
14	6.1	139.0	3.3	6.5	*	20.6	30.0	0.30	102.0	1.65	200.6	6.21

Remarks

TRD-80

Table No. 11

Lab. No. 50-82-R County Bexar Hwy. 346 Project

Material 13" Gravel Base Identification

Description

Opt. Moist. 5.8 Opt. Dry Density 138.9 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
2	5.7	138.4	5.7	6.2	Small	0.0	6.0	0.35	14.0	1.0	21.7	1.21
7	5.8	138.7	5.5	6.3	*	3.6	14.0	0.50	34.0	1.30	63.5	4.75
5	5.8	138.8	5.4	6.4	*	5.6	12.0	0.30	33.0	1.25	78.8	4.50
8	5.8	138.9	5.4	6.3	*	10.6	26.0	0.65	60.0	1.95	103.5	4.51
4	5.8	139.1	5.7	6.2	*	15.6	36.0	0.65	88.0	2.2	149.5	5.80
6	5.8	139.6	5.3	6.1	*	20.6	54.0	1.05	100.0	2.15	181.9	6.07

Remarks

TRD-80

Table No. 10

Lab. No. 50-81-R County Hwy. Loop 13 Project

Material Subgrade Soil Identification

Description Near Kelly Field Overpass

Opt. Moist. 24.8 Opt. Dry Density 92.8 at Comp. Effort 6.63 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
11	23.5	93.7	25.7	31.3	5.0	0	0.5	0.0	8.0	0.40	14.1	1.37
10	25.2	92.4	25.0	30.8	4.5	3.6	5.0	0.15	14.0	0.55	23.8	2.73
12	25.0	92.6	25.1	30.2	4.9	5.6	8.0	0.21	17.0	0.60	27.9	2.62
5	25.5	92.3	23.7	30.8	5.0	10.6	4.5	0.0	21.0	0.80	34.3	4.11
8	24.9	92.8	24.1	30.3	4.4	15.6	16.0	0.35	24.0	0.70	44.9	4.35
9	24.9	93.1	24.4	30.5	5.2	20.6	10.0	0.0	26.0	0.75	43.5	3.70

Remarks

TRD-80

Table No. 12

Lab. No. 50-83-R County Hwy. 346 Project

Material Subgrade Soil Identification

Description

Opt. Moist. 10.2 Opt. Dry Density 120.3 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
2	10.2	120.1	3.6	10.6	Small	0	10.0	0.50	17.5	0.90	28.0	2.19
5	10.2	120.2	3.4	10.7	*	3.6	12.0	0.25	31.0	0.90	59.4	2.79
6	10.3	120.2	3.6	10.6	*	5.6	12.0	0.25	35.5	0.90	73.5	3.17
8	10.3	120.3	3.5	10.5	*	10.6	22.0	0.40	46.0	0.80	106.0	3.56
4	10.1	120.4	3.3	10.8	*	15.6	23.0	0.35	62.0	0.95	121.6	3.67
7	10.2	120.4	3.5	10.5	*	20.6	28.0	0.30	77.0	0.95	156.0	3.56

Remarks

THD-80

Table No. 13

Lab. No. 50-90-R County Floyd Hwy. U.S. 70 Project

Material 9" Caliche Base Identification Station 330 + 15

Description

Opt. Moist. 11.3 Opt. Dry Density 120.4 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	Straight Portion From: % Strain	Straight Portion To: PSI Unit Stress	Straight Portion To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
9	11.3	120.1	7.7	13.2	Small	0.0	9.0	0.35	18.0	0.9	24.0	1.53
5	11.2	120.3	9.0	13.5	*	3.6	18.0	0.5	29.0	1.05	48.2	3.31
6	11.3	120.1	7.7	11.8	*	5.6	22.0	0.5	48.0	1.10	69.5	2.78
8	11.2	120.7	7.5	13.1	*	10.6	26.0	0.6	52.0	1.50	79.5	6.03
7	11.3	120.6	7.6	12.9	*	15.6	30.0	0.6	54.0	1.20	104.4	6.66
3	11.6	120.6	7.7	13.1	*	20.6	34.0	0.4	62.0	1.30	119.8	8.19

Remarks

THD-80

Table No. 15

Lab. No. 50-92-R County Crosby Hwy. U.S. 62 Project

Material 7" Caliche Base Identification

Description 1 Mily South Floyd-Crosby County Line

Opt. Moist. 12.6 Opt. Dry Density 116.0 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	Straight Portion From: % Strain	Straight Portion To: PSI Unit Stress	Straight Portion To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
9	12.6	115.6	11.5	16.2	Small	0.0	16.0	0.80	26.0	1.55	28.7	2.23
7	12.5	115.9	11.6	15.9	*	3.6	19.0	0.6	30.0	1.4	47.7	4.10
5	12.6	115.8	11.9	16.0	*	5.6	19.0	0.6	31.0	1.2	54.2	4.58
10	12.6	115.8	11.7	16.2	*	10.6	25.0	0.6	41.0	1.25	70.9	5.21
6	12.5	116.2	11.7	16.4	*	15.6	14.0	0.3	44.0	1.15	83.0	5.72
8	12.5	116.7	11.8	15.8	*	20.6	16.0	0.2	56.0	1.80	98.0	5.75

Remarks

THD 80

Table No. 14

Lab. No. 50-91-R County Floyd Hwy. U.S. 70 Project

Material Subgrade Identification

Description Clay Soil - Subgrade sampled from R.O.W. 10 miles East of Plainview.

Station 330 + 15

Opt. Moist. 18.9 Opt. Dry Density 104.6 at Comp. Effort 6.63 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	Straight Portion From: % Strain	Straight Portion To: PSI Unit Stress	Straight Portion To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
4	18.7	104.5	18.7	21.8	2.87	0.0	0.5	0.0	9.5	0.25	16.5	1.15
8	19.2	104.3	19.3	22.1	2.74	3.8	1.5	0.0	12.5	0.40	24.7	3.19
7	19.1	104.2	19.0	22.3	2.78	5.8	2.0	0.0	14.0	0.40	27.1	2.80
5	18.7	104.8	18.4	21.7	2.89	10.8	4.2	0.0	21.0	0.48	38.5	3.96
2	18.7	104.8	18.7	21.4	2.55	15.8	6.8	0.0	27.0	0.60	46.6	4.36
6	18.9	105.4	18.7	21.5	2.81	20.8	10.1	0.0	33.0	0.70	52.2	4.64

Remarks

THD-80

Table No. 16

Lab. No. 50-93-R County Crosby Hwy. U.S. 62 Project

Material Subgrade Soil Identification

Description Sampled from R.O.W. one mile South Floyd-Crosby County Line

Opt. Moist. 14.9 Opt. Dry Density 112.3 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capil-larity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	Straight Portion From: % Strain	Straight Portion To: PSI Unit Stress	Straight Portion To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
1	14.5	113.9	15.7	17.3	3.78	0	0.0	0.0	7.0	0.30	18.8	2.35
4	15.0	112.5	14.4	18.1	3.15	3.7	1.5	0.0	12.0	0.40	28.2	3.96
2	15.9	112.4	16.8	18.0	5.29	5.6	2.2	0.0	13.0	0.45	36.6	5.46
6	15.5	112.1	14.8	18.5	2.40	10.6	4.5	0.0	18.0	0.50	46.1	6.45
7	14.6	112.6	14.1	17.9	2.44	15.6	7.0	0.0	26.0	0.75	49.8	5.58
8	15.0	112.2	14.6	18.4	4.00	20.7	11.0	0.0	34.5	0.85	55.6	4.08

Remarks

TRD-80

Table No. 17

Lab. No. 49-40-R County Travis Hwy. U.S. 290 Project

Material 10" Gravel Base Identification

Description Sampled from R.O.W. East of Manor

Opt. Moist. 5.7 Opt. Dry Density 135.8 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capillarity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
4	5.6	135.8	2.7	6.2	Small	0	5.0	0.25	12.0	0.70	14.6	1.16
5	5.6	135.3	2.9	6.2	*	3.6	14.0	0.30	42.5	0.80	59.5	1.93
6	5.7	135.0	3.0	6.2	*	5.6	14.0	0.20	54.0	0.80	86.8	2.06
7	5.7	136.4	3.1	5.9	*	10.6	12.0	0.10	106.0	1.10	133.0	2.60
8	5.6	135.4	2.8	6.2	*	15.6	10.0	0.30	99.5	0.75	145.9	2.06
10	5.7	136.0	3.0	6.1	*	20.6	40.0	0.30	121.0	0.95	179.8	2.98

Remarks

TRD-80

Table No. 19

Lab. No. 49-14-R County Bastrop Hwy. 290 Project

Material 8" Crushed Stone Identification

Description Crushed Stone from Onion Creek

Pit Near Austin.

Opt. Moist. 10.0 Opt. Dry Density 124.8 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capillarity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
5	10.1	124.6	3.6	9.5	Small	0.0	7.5	0.0	23.0	0.60	47.0	1.95
6	10.3	124.8	2.9	9.5	*	3.6	35.0	0.15	75.0	1.10	110.8	2.92
3	9.3	124.0	2.6	9.6	*	5.4	37.5	0.40	83.0	1.10	147.1	3.54
7	10.1	125.0	2.9	9.4	*	10.6	10.0	0.0	115.0	1.55	176.8	3.24
8	10.2	124.9	3.4	9.6	*	15.6	15.0	0.0	137.5	1.20	236.5	3.51
9	10.1	125.3	2.9	9.2	*	20.6	15.0	0.0	157.5	1.40	239.9	3.39

Remarks

TRD-80

Table No. 18

Lab. No. 39-11-RS County Travis Hwy. U.S. 290 Project

Material Identification

Description Sampled from R.O.W. East of Manor

Opt. Moist. 27.1 Opt. Dry Density 90.0 at Comp. Effort 5.25 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capillarity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
55	26.8	90.0	26.7	34.5	8.2	3.9	2.5	0.0	11.0	0.35	18.1	1.7
56	27.1	90.3	26.8	34.6	7.6	5.9	3.5	0.0	12.0	0.40	21.5	2.4
57	27.1	90.0	27.1	34.7	7.7	10.9	5.5	0.0	13.0	0.35	28.1	2.8
58	27.3	89.7	27.1	34.6	6.7	15.9	13.5	0.15	24.0	0.70	40.2	3.3
59	27.0	90.1	26.9	34.2	7.8	20.9	16.0	0.15	28.0	0.80	43.4	3.3

Remarks

TRD-80

Table No. 20

Lab. No. 47-136-E County Bastrop Hwy. 290 Project

Material Sand - Clay Identification

Description Typical Sand - Clay hauled from cuts for Select Material

Opt. Moist. 12.9 Opt. Dry Density 114.4 at Comp. Effort 13.26 ft.lb./cu.ft.

Spec. No.	Molding Data: % Moist. Dry Weight	Molding Data: Dry Den. Lbs./Cu.Ft.	Curing Data Moist. Cont.: % After Dry.	Curing Data Moist. Cont.: % Abs. After Capillarity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress-Strain Relations, Straight Portion From: PSI Unit Stress	From: % Strain	To: PSI Unit Stress	To: % Strain	Ultimate: PSI Unit Stress	Ultimate: % Strain
23	12.8	114.5	6.3	13.7	Small	3.7	11.5	0.75	14.5	1.10	41.3	5.05
25	12.9	114.7	6.0	13.8	*	5.7	14.0	0.70	20.0	1.10	54.3	5.85
24	12.9	114.1	6.4	13.9	*	8.2	18.0	0.70	23.0	0.90	64.0	5.82
26	13.0	114.1	6.6	13.9	*	10.7	20.0	0.60	30.0	1.00	77.9	6.60
27	12.9	114.8	5.9	13.7	*	15.7	24.0	0.50	38.0	0.85	103.6	7.28
28	12.9	114.4	6.4	13.9	*	20.7	14.0	0.0	50.0	0.80	125.8	6.22

Remarks

APPENDIX

TRIAXIAL COMPRESSION TEST, TEXAS HIGHWAY DEPARTMENT, THD-80

FOREWORD

This triaxial compression test procedure has been developed on the basis of studies pertaining to the factors which influence the strength test results. The test method is applied, Part I, to remolded specimens of disturbed materials such as soils or aggregate bearing materials with a top size of 2 inches for the largest particles, and Part II, to undisturbed cores from roadway or foundation material from the site of a proposed structure.

Figure 1.

APPARATUS

1. Apparatus used in T. H. D. Testing Procedures No. 53 and 83.

2. Axial Cells — light weight stainless steel cylinders; inside diameter 6¾"; fitted with a standard air valuc; inside of each cylinder is a tubular rubber membrane, 6 in. diameter. See Figure 1 (small cells for bridge cores).

3. Aspirator or other vacuum pump.

4. Constant pressure air supply. See Figure 2.

5. Air compressor or suitable pump.

6. Auxiliary compressed air storage tank with pressure gauges, valves, and air lines. See Figure 4.

7. Light weights for surcharge loads.

8. Micrometer dial, calibrated in 0.001 in., with support.

9. Dial housing to transmit load and cylindrical loading block. See Figure 4.

10. Calibrated proving rings.

PART I

TEST PROCEDURE FOR DISTURBED REMOLDED MATERIALS

Preparation of Sample.

Prepare the material according to the method given in THD-53, Part II.

Moisture-Density.

Use the method outlined under THD-83 and determine the optimum moisture and the maximum density. The compactive effort specified for the type of material being tested should be used. Store specimens in damp room if it is desirable to use them in test.

Specimens Molded at Optimum Moisture for Testing

1. Mold six specimens 6" in diameter and 8" in height at the optimum moisture and density. These specimens should be made as nearly the same as possible. Any test series of specimens, along with the ones made for the moisture-density curve, should be molded at the same compactive effort. If it is desirable to try different compactive effort, a complete new set of specimens must be molded.

2. Immediately after extruding from the mold, the specimens with top and

bottom stones in place are stored in the moist room over night. The purpose of this over-night storage is to permit the moisture to equalize in all parts of the specimens; therefore, the specimens should not come in direct contact with capillary or surface water. Record data on form shown in Figure 5.

Figure 2.

Drying of Specimens

After the molding moisture has had time to equalize, the specimens are returned to the laboratory and dried according to the type of material.

1. In the case of a flexible base material that will not develop shrinkage cracks, the specimens are placed in a drying oven for 8 hours (about one-half of the molding moisture will be removed) at a temperature of 140 F. These specimens should be cooled for at least 8 hours before following the next step (capillarity).

2. For a doubtful material, it might be placed in a drying oven (140 F.) and checked frequently for the appearance of shrinkage cracks. If cracks appear, some drying at room temperature may be allowed during the cooling period.

3. In the case of very plastic clay subgrade soil that will crack badly while shrinking, air dry at room temperature until cracks develop.

Excessive cracking (in steps 2 and 3) will damage the test specimens.

Subjecting Specimens to Capillarity

1. The specimens are ready to be weighed, measured and prepared for capillarity. The porous stones are not to be removed from the specimens for any reason until after the specimens have been tested.

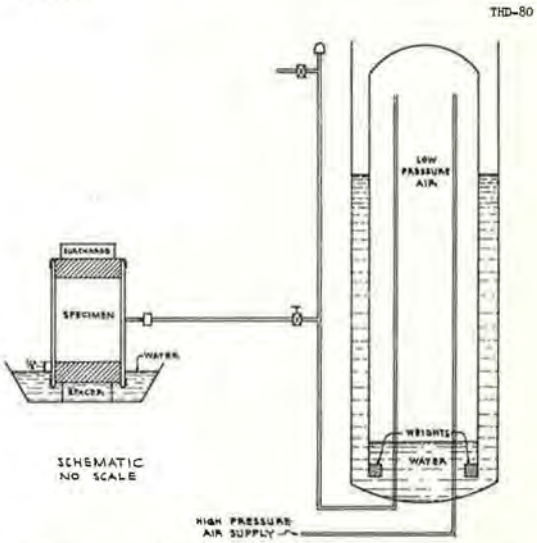


Figure 3. Diagram of equipment used during capillary wetting.

2. Each specimen, with porous stones in place, is wrapped with a piece of slitted filter paper and enclosed in a pressure cell. This is done by applying a partial vacuum to the pressure cell, slide it over the specimen and release vacuum.

3. Place the assembly in a pan and adjust the water level on the lower porous stone to a distance of one-half inch below the bottom of the specimens. See Figure 3 for schematic drawing of set up.

4. The cell is then connected to the constant pressure air manifold and subjected to the usual lateral pressure of 1 psi. This constant pressure shall be maintained throughout the period of capillarity.

5. Next, place an appropriate vertical surcharge weight (which will depend upon the condition of the proposed use of the material) to the upper porous stone. For

flexible base materials use one-half pound per square inch and for subgrade soils use one pound per square inch. The upper porous stone is considered as part of the surcharge weight.

6. After the specimens have been in capillarity for (10 days for materials having a P. I. below 15) a period of time in days equal to the P. I. for all materials with P. I. above 15, they are prepared for testing. The specimens should be kept in a damp room during the time they are subjected to capillarity. See Figure 2. Record data as shown in Figure 6.

Preparing Specimens for Testing.

1. Disconnect air hose from cell and remove surcharge weight. Return specimens to laboratory for testing.

2. Remove cell from specimen and discard filter paper.

3. Measure the circumference of the specimens by use of a tape or strip of paper. Measure the height of specimen including the stones, and record as "height out of capillarity". Record the height of each stone.

4. Weigh specimens in order to obtain the percentage of absorption.

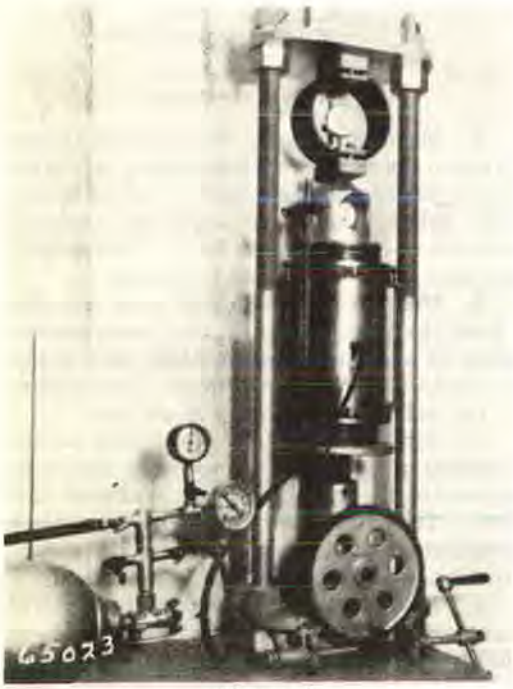


Figure 4.

TRIAXIAL COMPRESSION TEST DATA SHEET
FOR COMPACTING SPECIMENS

T-D-80

Sample #						
Date Molded						
Compactive Effort						
Total % H_2O						
Pounds Air Dry						
Pounds H_2O Desired						
Less Pounds Hygro.						
Wt. Water & Jar						
Tare Wt. of Jar						
Mold No.						
Wet Wt. Spec. & Mold						
Tare Wt. Mold						
Wet Wt. Spec.						
Height Mold						
Dial Reference						
Dial Reading						
Height Specimen						
Vol. per Lin. In.						
Vol. of Spec.						
Wet Density Spec.						
Dry Wt. Pan & Spec.						
Tare Wt. Pan						
Dry Wt. Mat'l.						
Wt. H_2O						
% H_2O on Total						
Dry Density						
Remarks:						

Figure 5.

5. Replace the axial cells on the specimens and they are ready to be tested.

Testing the Specimens

Record results as shown in Figure 7. In brief, the specimens are tested in compression while being subjected to their assigned constant lateral pressure. The rate of deformation to use is 0.15 inch per minute. Simultaneous readings of load and deformation are to be taken at intervals of 0.01 inch deformation. The procedure described below applies to both a hand operated or motor driven gear press equipped with a deformation gauge and a proving ring. See Figure 4.

1. Disengage the worm gear drive and crank the press down far enough to have room to place specimen and loading blocks in the press.

2. Center specimen (with upper and lower loading blocks in place) in press. Adjust the deformation gauge in such a manner that it will be down against the center of top loading blocks and also compressed for almost the total length of travel of the stem. The gauge must be placed in this position because during the compression of the specimens it moves away from the gauge. Set dial on the de-

TRIAXIAL COMPRESSION TEST DATA SHEET
FOR CAPILLARITY AND VOLUME CHANGE

THD-80

Sample #						
Cell #						
Lbs. of Added surcharge						
Date Molded						
Date in air dryer						
Date in capillarity						
Date out capillarity						
Height in capillarity						
Height out capillarity						
Difference in height						
% swell						
Weight after oven air dry						
Dry weight stones & plate						
Dry cell						
Dry filter paper						
Oured dry weight sample						
Dry weight sample						
Weight moisture in sample						
% moisture to capillarity						
Weight after capillarity						
Weight wet stones & plate						
Weight wet cell						
Weight wet filter paper						
Weight wet sample						
Dry weight sample		*				
Weight moisture in sample						
% moisture after capillarity						
Remarks:						

Figure 6.

TRIAXIAL COMPRESSION TEST DATA SHEET
FOR STRESS-STRAIN CURVE

THD-80

Lab. No.
Date Molded
Date Tested
No. Days in Cap.
Spec. No.
Est. Press.

Area
A/A =
*T/A =
*T.lbs. per sq.in. compaction
Init. Ht. =

Circum.
Avg. Dia.
Strain Rate =
Ht. over Stones
Stones
A
Ht. =
Init. Wt. =

Strain factor = .01 / New Ht. = .01 =

Dead Load
Deformation

Load*	Uncorr. Stress	% Strain	Corr. Stress
.01			
.02			
.03			
.04			
.05			
.06			
.07			
.08			
.09			
.10			
.11			
.12			
.13			
.14			
.15			
.16			
.17			
.18			
.19			
.20			
.21			
.22			
.23			
.24			
.25			
.26			
.27			

*Austin Lab proving ring factor. Other rings will have various factors.
*Load may be either in pounds or proving ring readings.

Figure 7.

formation gauge to read zero or on an even tenth.

3. Set the special bell housing over the deformation gauge but do not allow it to touch the gauge or its mounting. Raise the press by means of the hand crank, center and set the ball on the housing into the socket of the proving ring. It should be noted that the compressive stress will necessarily be applied along a vertical line through the center of the ball mounted in the bell housing. Read the deformation gauge and record as deformation under dead load.

4. Connect the air line to the axial cell and apply lateral pressure to the specimen. The usual lateral pressures used for a series of tests are 0, 3, 5, 10, 15 and 20 psi. The lateral pressure applied by the air will tend to change the initial reading of the deformation gauge. Load the specimen as the air pressure is applied until the deformation gauge reads the same as recorded in step 3, above. The proving ring gauge is now read and the reading entered in the load column opposite the initial deformation reading.

5. The actual test is now ready to be run. The dial gauge on the proving ring is read for each 0.01 of an inch deformation. This procedure is continued to the point of failure which is reached when the needle on the proving ring gauge remains the same or drops off.

6. All of the above procedure applies to the unconfined specimen except that no air or axial cell is used.

7. The specimens are broken up, then placed in tared pans and dried to constant weight at 230 F. The pans of

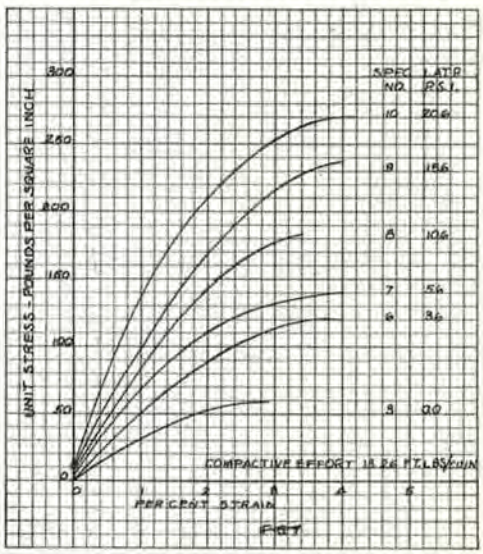


Figure 8. Stress-strain diagram.

material are reweighed to obtain the dry weight. The stones are weighed, dried, and the dry weight obtained.

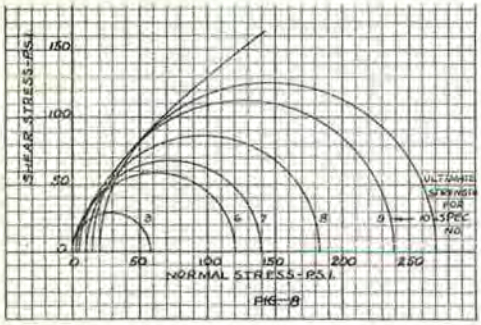


Figure 9. Mohr's diagram.

Calculations

1. Calculate molding moisture and dry density of each specimen.

2. Compute the percentage of swell and absorption after capillarity.

$$\% \text{ Volumetric Swell} = \frac{\text{(Volume Change)}}{\text{(Molded Volume)}} 100$$

3. Calculate data for stress-strain curve.

For each individual specimen tested, terms and symbols are defined as follows:

P = total vertical load on the specimen at any given deformation, expressed in pounds. It is the sum of the applied load measured by the weighing mechanism plus the dead weight of the upper stone, loading block and dial housing.

A = the original area of cross-section of the specimen expressed in square inches calculated from measured diameter or circumference = π (radius)^2.

h = the original height of the specimen in inches, measured before beginning the test.

d = the total vertical deformation at the given instant, measured in inches by the deformation dial.

%S = percent strain - the relation of the deformation at the given instant to the original height, expressed in percent, calculated from the formula %S = 100 x d/h.

P/A = the nominal vertical unit stress at any given deformation expressed in pounds per square inch.

p = the corrected vertical unit stress in pounds per square inch. A correction is necessary because the area of the cross-section increases as the specimen is pressed down. Assuming that the specimen deforms at constant volume, p = P/A x (1 - %S/100).

Plotting Curves and Diagrams

1. Plot molding moisture against dry density as shown in THD-83.

2. Plot stress-strain curve as shown in Figure 8 for each increment of deformation. This is not mandatory but desirable.

3. The Mohr's diagram of stress (Figure 9) is constructed upon coordinate axes in which ordinates represent shear-stress and abscissae represent normal stress, both expressed as pounds per square inch and both drawn to the same scale.

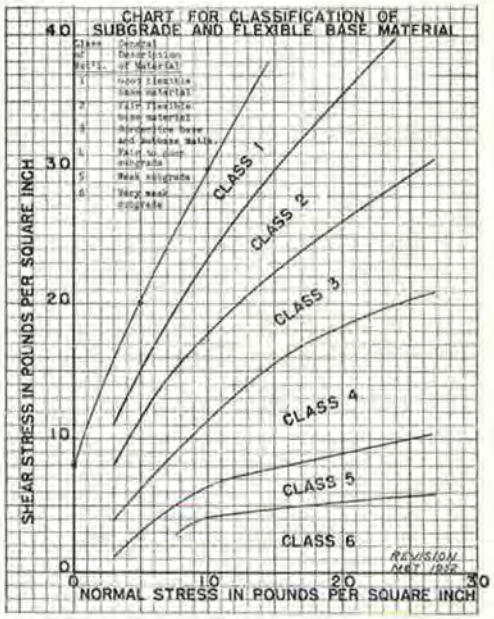


Figure 10.

σ_m = the minor principal stress which is the constant lateral pressure applied to the specimen during an individual test, and σ_1 = the major principal stress which is the ultimate compressive strength (the ultimate value of p) of the specimen at the given lateral pressure. Each individual test will be represented by one stress circle constructed as follows:

On the axis of normal stress plot σ_m.

On the same axis plot τ.

Construct a semi-circle on the abscissa base line with its center at a distance equal to $(\sigma_I + \sigma_{III})/2$ from the origin, with its radius equal to $(\sigma_I - \sigma_{III})/2$ and cutting the base line at σ_I and σ_{III}.

Classification of Material and Interpretation

Transfer the rupture envelope on to the chart for classification of subgrade and flexible base material (Fig. 10) and classify.

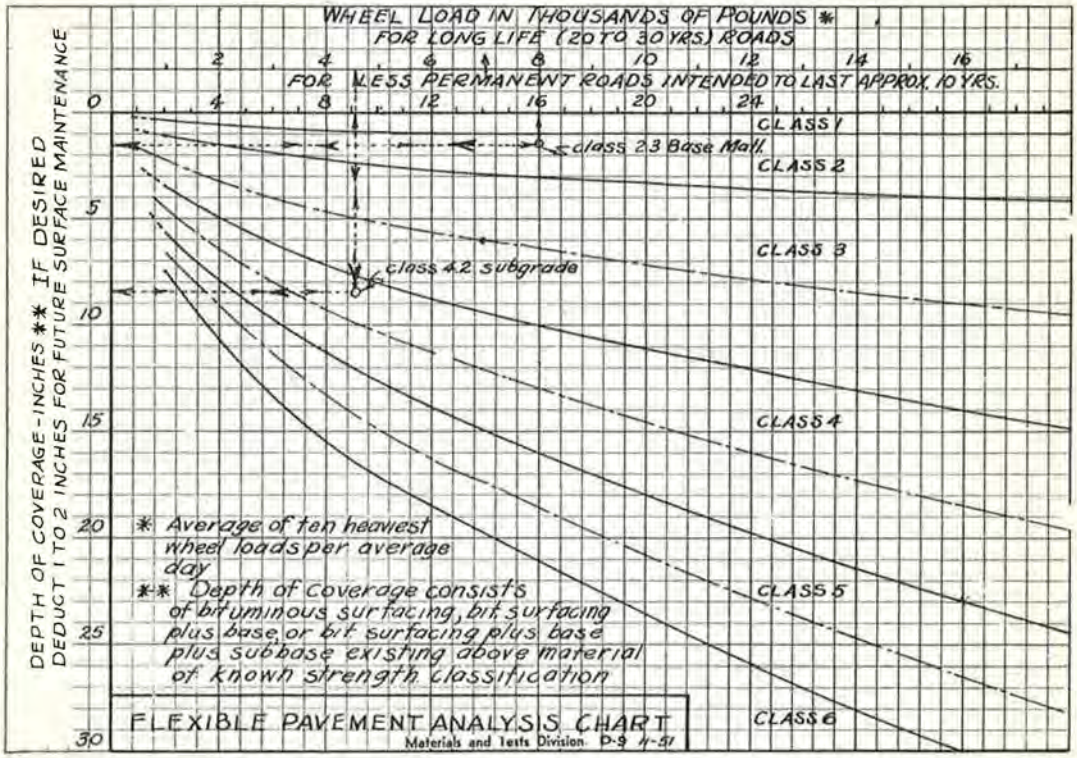


Figure 11.

Repeat these steps for each specimen tested. The test procedure calls for a minimum of 5 specimens, each tested at a different lateral pressure, in order to provide data for enough stress circles to define the rupture envelope on the Mohr diagram.

Draw a line tangent to all of the stress circles. This line, called the "Rupture Envelope", represents the shearing strength of the material under various conditions. It is practically impossible to avoid compacting an occasional specimen that is not identical with the other specimens in the same set with regard to moisture, density and particle arrangement. Triaxial test results from such specimens may be out of line. In drawing the rupture envelope, disregard any stress circles that obviously are out of line with others of the same set.

There appears to be no necessity for further differentiation of Class 1 materials. However, in Classes 2 through 6 the rupture envelope may fall between class limits so that interpolation is necessary to determine the depth of cover required. Between class boundaries the weakest or most critical point on the rupture envelope governs, i. e., the point nearest the lower boundary of the class.

Using the classification of material and the design wheel load, determine the depth of flexible base from flexible pavement analysis chart (Fig. No. 11). Careful consideration of road service life should be made and only long life design should be used in urban sections.

Reporting of Test Results

As a minimum, a report should include

the identification, soil constants and gradation on Form 476A, a summarization of data in the attached tabulation (Fig. 12) and a classification plotting on Figure 10.

Note: For control of compaction see THD-110.

THD-80

Table No. ___

Lab. No. _____ County _____ Hwy. _____ Project _____

Material _____ Identification _____

Description _____

Opt. Moist. _____ Opt. Dry Density _____ at Comp. Effort _____ ft.lb./cu.ft.

Spec. No.	Molding Data		Curing Data				Stress-Strain Relations					
			Moist. Cont.				Straight Portion				Ultimate	
							From		To			
	% Moist. Dry Weight	Dry Den. lbs./ Cu.Ft	% After Dry.	% Abs. After Capillarity	% Vol. Swell	Appl. Lat. Pres. P.S.I.	Stress	% Strain	Stress	% Strain	Stress	% Strain

Remarks

Figure 12.

PART II

TEST PROCEDURE FOR UNDISTURBED CORES FROM ROADWAY OR BRIDGE FOUNDATION

Preparation of Specimens for Testing

1. Remove metal or cloth and paraffin protective cover and examine core. Classify core as to type of material, color, structure, and moisture content.

2. Cut off a piece of the core, the length of which shall be at least twice the diameter of finished test specimen. Coat this specimen and remainder of core with paraffin to prevent loss of moisture.

3. By means of a knife, saw or other cutting tools, make the ends parallel to each other and square with the center line of the specimen.

4. Place a circular porous stone on the top and bottom of specimen. In cases where the specimen is larger than the stones or if the sides are irregular, trim sides of specimen flush with the top and bottom stones.

5. Immediately after trimming the cylindrical specimen, weigh, measure circumference and height, and place specimen in testing cell. If the lateral pressure to be applied during testing is above 25 pounds per square inch, fasten retainer rings on the pressure cell.

6. Place the specimen in compression machine and apply lateral pressure (one pound p. s. i.) for each foot of overburden depth and additional increments of 5 to 10 p. s. i. over the range of the lateral pressures expected to develop due to loading.

7. Test the specimen by increasing the deformation load to failure. This load should be applied at a rate of 0.15 inch deformation of specimen and readings taken at each 0.01 of an inch deformation.

8. Release the load and remove specimen from pressure cell. Examine the break in the specimen.

9. Dry specimen at 230 F. and obtain dry weight.

10. Calculate dry density of core in pounds per cubic foot.

Interpretation

Prior to testing, undisturbed cores should be in equilibrium with respect to moisture and density under the conditions of proposed use. If cores are taken at a relatively great depth to represent the subgrade of flexible base in a proposed cut (not to be cut below grade and recompacted), the cores should be saturated under the proposed new surcharge before testing.

Relatively shallow cores, representing the subgrade under an existing, unbroken base, probably are in equilibrium and require no processing. If these shallow cores are from an uncovered subgrade, they should be subjected to capillary wetting under the proposed surcharge. A rather large number of cores may be required under the latter condition to arrive at average values. When cores representing subgrades of flexible pavements have been processed and tested, the rupture envelopes may be superimposed on the classification chart shown and may be judged according to the wheel loads and base depths shown in Figure 11.

Application of Strength Versus Stress for Foundations

Figure 13 shows the plotting of Mohr's diagram of stress representing the strength tests on the undisturbed cores from the area of the footing. Superimposed on the diagram is a stress circle (Circle A) representing the total vertical and radial stresses at the critical point on the axis of the loaded area. These stresses were estimated as shown in the upper part of Figure 13 and in the "Example of Application" in the latter part of this report. The stress line, shown in Figure 13 as a dashed line, is tangent to this circle and is constructed in accordance with step 2, below. All stress circles representing various loadings on this size footing and subject to this particular surcharge will be tangent to the stress line. The factor of safety against failure of the soil is assumed to be the ratio; ultimate load soil will support divided by the applied load. This factor can be calculated from soil mechanics formulae if definite values of cohesion and angle of internal friction are known. In order to determine definite values of cohesion and friction, it is necessary that Mohr's envelope of failure be a straight line. Since this is not the case for many soils foundation materials, the use of a graphical method is preferred. The procedure for determining this factor of safety is as follows:

1. Draw the rupture envelope representing the strength of the soil foundation material.
2. Beginning at a point on the normal stress axis, representing the hydrostatic surcharge (U_Z from Fig. 13), draw a straight line making an angle of 33. 8 deg. with the normal stress axis.
3. By trial and error, find the stress circle, if any, that is tangent to both the 33. 8-deg. line and the rupture envelope.
4. Read the major principal stress (or read minor principal stress).
5. Subtract the hydrostatic surcharge U_Z from the major principal stress and divide by 0. 808 (or subtract U_Z from minor principal stress and divide by 0. 230).
6. The ratio of the load determined in Step 5 to the applied load is the factor of safety with respect to load.

In designs made with factors of safety of $1\frac{1}{2}$ to $2\frac{1}{2}$ there have been no excessive settlements in the structures so designed. The above factor of safety becomes infinitely great when soil foundation materials have angles of internal friction in excess of approximately 34 deg.

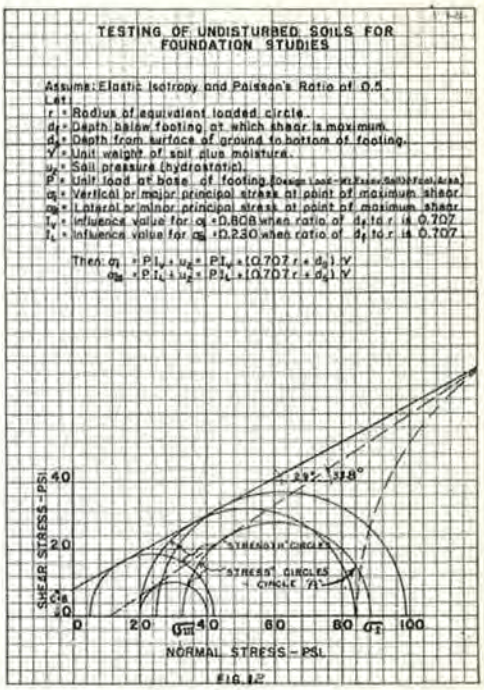


Figure 13.

Example of Application to Foundation Design

The following example is based on data obtained for a grade separation structure where the highway passes underneath the railroad. It is desired to place footings approximately ten feet below the highway grade line in a sand-clay cut which has a wet unit weight of 125 lb. per cu. ft. This probably is the minimum depth of penetration because the roadway ditches will drain both surface and underground water. The problem is to determine the size of an adequate spread footing for this structure which has a pier load of 660 tons. Since only a few footings are needed, underreamed footings probably are not feasible. Assuming that each pier is to rest on two, 7-foot square footings on 21-foot centers, and the test results showing Mohr's envelope of failure for the soil involved are as shown in Figure 13, the problem may be solved as follows:

1. The radius "r" of a circle equivalent

Texas Highway Department
Form 476A 7-53-5m

84005-753-5m

SOILS AND BASE MATERIALS TEST REPORT

Laboratory No. _____
Date Rec'd _____ Reported _____
Engineer _____
Address _____
Contractor _____
Sampler H. S. Gillette & C. McDowell
Sampler's Title _____
Sampled From Roads
Producer _____
Quantity Represented by Sample _____
Has been Used on _____

Control Number | Section Number | Job Number
County 16 | Federal Project No. | Highway No.
District No. | I.P.E. No. | Req. No. | Date Sampled

Specification Item No. _____
Material from Property of _____
Proposed for Use as _____

Lab. No.	LL	PI	FME	CME	SL	LS	SR	Class	Soil Binder	% Moist.	Str. Class
50-76-R	32	18	23	-	19	6.8	1.74	A-6-2	26	- --	1.0
77	40	23	25	-	16	11.5	1.86	A-6	100	14.8	4.9
72	38	15	30	-	25	6.0	1.61	A-4-7	49	--	3.1
73	30	15	27	-	17	6.6	1.80	A-2	89	9.4	3.4
74	49	22	34	-	28	8.9	1.52	A-7	45	--	3.3
75	56	35	28	-	14	17.6	1.90	A-7	98	18.1	4.8

PERCENT RETAINED ON

Lab. No.	Round Opening Screens, Opening in Inches									Square Mesh Screens, Sieve Numbers						Grain Diam. in Millimeters			Specific Gravity
	3½	3	2½	2	1½	1	¾	½	¼	10	20	40	60	100	200	.05	.005	.001	
50-76-R					4	11	16	25	44	59	71	74	75	77	88	89	93	97	2.64
77													1	3	32	45	73	87	2.65
72					2	4	8	12	22	33	43	51	56	61	67	70	90	98	2.64
73									1	2	3	11	25	40	65	73	90	96	2.60
74					1	4	9	15	27	42	51	55	59	62	67	70	93	97	2.65
75											0	2	9	25	51	56	66	83	2.66

SAMPLE IDENTIFICATION

Lab. No.	Identification Marks	Location—Properties—Station Numbers	Type of Materials
50-76-R	No, 1, FM-136	Refugio Co. (between Bayside and Woodsboro)	5½" of shell base Subgrade soil
77	" "		
72	No. 3 US 59	Business route in Mathis, 3 blks.N. int. of business rt. and regular US 59	10" of caliche base Subgrade soil
73	" "		
74	No. 4, St. 202	3 Mi.E. of Beeville	7" of caliche base Subgrade soil
75	" "		

Exhibit A.

Texas Highway Department
Form 478A 7-52-5m

84005-752-5m

SOILS AND BASE MATERIALS TEST REPORT

Laboratory No. _____
Date Rec'd _____ Reported _____
Engineer _____
Address _____
Contractor _____
Sampler H. S. Gillette & C. McDowell
Sampler's Title _____
Sampled From Roads
Producer _____
Quantity Represented by Sample _____
Has been Used on _____

Control Number | Section Number | Job Number
County | Federal Project No. | Highway No.
District No. | I.P.E. No. | Req. No. | Date Sampled

Specification Item No. _____
Material from Property of _____
Proposed for Use as _____

Lab. No.	LL	PI	FME	CME	SL	LS	SR	Class	Soil Binder	% Moist.	Str. Class
50-82-E	34	20	22	-	16	9.3	1.91	A-6-2	27	-	3.1
83	24	8	18	-	17	4.0	1.79	A-2	96	8.2	3.1
78	31	14	22	-	18	6.8	1.82	A-2	36	-	2.8
84	82	56	49	-	12	25.8	2.05	A-7	86	23.6	5.2
80	29	15	21	-	16	6.8	1.87	A-2	31	--	2.7
81	66	41	39	-	15	20.2	1.90	A-7	96	24.6	4.7
49-40-R	24	7	20	-	17	4.0	1.78	A-2	92	--	3.0
39-11-MR	74	45	45	-	12	24.0	2.00	A-7	97	31.	4.9

PERCENT RETAINED ON

Lab. No.	Round Opening Screens, Opening in Inches									Square Mesh Screens, Sieve Numbers						Grain Diam. in Millimeters			Specific Gravity
	3½	3	2½	2	1½	1	¾	½	¼	10	20	40	60	100	200	.05	.005	.001	
50-82-R				3	7	19	27	40	56	67	72	73	76	79	83	85	92	97	2.70
83									1	2	3	4	7	27	63	69	83	92	2.60
78					8	19	28	37	51	59	62	64	66	67	69	71	90	98	2.65
84							0	5	8	12	13	14	14	16	22	27	61	83	2.66
80					3	14	22	34	47	59	64	69	75	80	84	86	98	99	2.75
81										1	3	4	5	7	16	20	63	83	2.71
49-40-R					8	17	21	28	38	51	62	68	73	82	90				2.60
39-11-MR												3	3	4	5	12	54	77	2.71

SAMPLE IDENTIFICATION

Lab. No.	Identification Marks	Location—Properties—Station Numbers	Type of Materials
50-82-R	No. 5 St. 346	Bexar Co. Sta. 888,12 Mi.S.Int.Loop	13" Gravel Base
83	" "	13 and 346	Subgrade Soil
50-78-R	No. 6 Loop 13	2000' N.Main gate,Lakcland Air Base	13" Gravel Base
84	" "		Subgrade Soil
50-80-R	Np. 7, Loop 13	2000' E. of Kelly Field Overpass	12" Gravel Base
81	" "		Subgrade Soil
49-40-R	US 290 Travis Co.	East of Manor	10" Gravel Base
39-11-MR	" "		Subgrade Soil.

Exhibit B.

Texas Highway Department
Form 476A 7-58-5m

84005-753-5m

SOILS AND BASE MATERIALS TEST REPORT

Laboratory No. _____
Date Rec'd _____ Reported _____
Engineer _____
Address _____
Contractor _____
Sampler H. S. Gillette & C. McDowell
Sampler's Title _____
Sampled From _____
Producer _____
Quantity Represented by Sample _____
Has been Used on _____

Control Number | Section Number | Job Number
County | Federal Project No. | Highway No.
District No. | I.P.E. No. | Req. No. | Date Sampled

Specification Item No. _____
Material from Property of _____
Proposed for Use as _____

Lab. No.	LL	PI	FME	CME	SL	LS	SR	Class	Soil Binder	% Moist.	Str. Class
50-90-R	35	18	23	-	18	8.5	1.76	-	48	-	3.1
91	34	19	22	-	16	8.7	1.86	A-7-4	100	9.2	4.6
92	35	17	26	-	20	7.6	1.75		59	-	3.4
93	36	20	25	-	15	10.5	1.87		100	10.6	4.4
49-14-R	22	6	19	-	15	4.1	1.89		28	-	1
47-137-E	30	7	23	-	25	2.7	1.59	A-2	98	-	3.4

PERCENT RETAINED ON

Lab. No.	Round Opening Screens									Square Mesh Screens						Grain Diam. in Millimeters			Specific Gravity
	Opening in Inches									Sieve Numbers									
	3½	3	2½	2	1½	1	¾	½	¼	10	20	40	60	100	200	.05	.005	.001	
50-90-R				0	7	19	24	30	37	44	49	52	54	63	77	80	90	98	2.64
91													3	10	22	39	78	92	2.68
92					2	5	8	13	24	33	38	41	43	50	63	70	88	97	2.65
93													2	11	27	48	78	92	2.65
49-14-R					13	25	31	39	48	56	65	72							
47-136-E											0	2	5	53	74	81	84	87	2.63

SAMPLE IDENTIFICATION

Lab. No.	Identification Marks	Location—Properties—Station Numbers	Type of Materials
50-90-R	No. 14 US 70	Floyd Co., 4 Mi.E. of Hale Co.Line	9" Caliche Base
91	" "	Sta. 330+15	Subgrade Soil
50-92-R	No. 15, US 62	Crosby Co. 1 Mi. S. Floyd-Crosby	7" Caliche Base
93	" "	Co. Line	Subgrade Soil
49-14-R	US 290	8" Crushed Stone Base	Flexible Base
47-136-E	"	Sampled from R.O.W. Cut	Subgrade Soil and Select Material

Exhibit C.

in area to a 7-foot square is equal to 3.95 feet.

2. From Figure 13:

$d_f = .707 \times 3.95 = 2.8'$

$d_s = 10'$

P = 330 tons plus weight of concrete pier minus weight of excavated soil,

$= 330 \times 2000 + (7 \times 7 \times 10)(150-125)$ divided by 49

= 13719 lb. per sq. ft. = 95.3 psi.

$I_V = .808$ (See Fig. 13)

$I_L = .230$ (See Fig. 13)

$\sigma_I = 95.3 \times .808 + 12.8 \times 125$ divided by 144 = 88.1 psi.

$\sigma_{III} = 95.3 \times .230 + 12.8 \times 125$ divided by 144 = 33.0 psi.

Factor of safety $= \frac{84-11.1}{.230}$ divided by applied load P (95.3 in this case) = 3.3

Approximate factor of safety for 6' x 6' footing $= (\frac{36}{49})\,3.3 = 2.4$

Approximate factor of safety for 5' x 5' footing $= (\frac{25}{49})\,3.3 = 1.6$

Therefore, size of footing should be 6' x 6', or greater.

DISCUSSION

RAYMOND C. HERNER, Chief, Airport Division, Technical Development and Evaluation Center, Civil Aeronautic Administration — Although we probably never shall eliminate the factors of experience and engineering judgment in consideration of any design problem, it is refreshing to note the increased use of strength tests and definite design criteria by the various highway departments. The Texas department has been one of the leaders in this movement. For several years it has had a flexible pavement design method based partly on theoretical concepts and partly on experience, with the triaxial test used for evaluation of subgrade and base course materials.

McDowell's excellent report now gives us an opportunity to see how well this design method is working. The results thus far are encouraging.

The writer has one suggestion in regard to evaluating traffic which might help in coordinating laboratory findings with service experience. There are many pavements which have stood up for years under comparatively light traffic, then have failed within a comparatively short period of time as loads increased. If the highest wheel loads are then averaged for the entire life of the pavement, we are likely to end up with a deceptively low average value for the load which caused the destruction.

It is the old problem of adding apples to oranges. Despite continuing efforts to do so, it is impossible to add heavy loads to light loads with any result except confusion. It would appear desirable then to average only loads within a comparatively narrow weight range in order to determine the critical load for design or evaluation purposes. Although frequency of loading must be considered also, it should not be allowed to obscure the effect of heavy loads.

McDowell's paper was particularly valuable because of the detailed test data given in the appendix. The writer found it interesting to compare the strength ratings of the materials as determined by the Texas test method with their ratings as determined by the CAA soil-classification method. The latter method is based entirely on mechanical analysis, liquid limit, and plasticity index. By plotting values from the two systems against each other, it was possible to establish a rough correlation as shown in Table A.

TABLE A

CAA Classification	Texas Classification
E-1	1
E-2	1.6
E-3	2.1
E-4	2.7
E-5	3.25
E-6	3.75
E-7	4.25
E-8	4.6
E-9	4.8
E-10	5.0
E-11	5.1
E-12	5.2

The correlation is fairly good for subgrade soils but is not so good for base course materials. This is not surprising, as the CAA classification is intended for evaluation of materials for subgrades rather than base courses.

It also was interesting to compare the Texas materials with those tested triaxially in the CAA's Load-Transmission Project (now being operated through the cooperation of the Navy Bureau of Yards and Docks). The strength range and characteristics of materials used in the Texas roads are comparable to those of materials used in the CAA tests if due allowance is made for the difference in height-diameter ratio of the triaxial specimens. The Texas Department of Highways uses a 6-by-8-inch specimen (H/D = 1.33) while the CAA uses a 10-by-20-inch specimen (H/D = 2.0) as standard.

A limited number of tests have been run by the CAA in order to determine the effect of specimen height. Average results for gravel and sand are given in Table B.

TABLE B

Height/Diameter Ratio	Indicated Strength Percentage of Standard Specimen
0.8	210
1.33 (Texas)	123
1.6	111
2.0 (CAA Std.)	100
3.0	86

It seems quite likely that the effect would be less pronounced on tests of cohesive soils, but would be greater on very coarse granular materials.

The writer is very pleased to have access to the information given in McDowell's paper, and hopes that further papers will be forthcoming from the same source as additional service experience is accumulated.