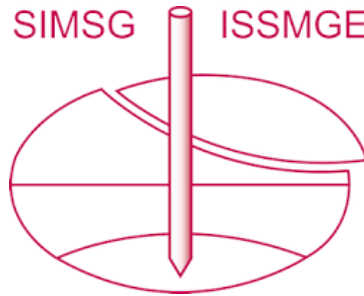


INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



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(2) 'Apparatus for test: (1) 1 four-inch spatula (stainless steel), (2) 1 four-inch evaporating dish, (3) 1 metal mould, preferably stainless—see Fig. 1 (author), (4) 1 drying oven that can be used to dry out samples between 200 and 225° F., (5) 1 thermometer graduated to 400° F. by 2 degrees intervals, (6) 1 grooving tool, (7) Vaseline for greasing shrinkage moulds, and (8) 1 stainless steel shrinkage gauge.'

(3) 'The importance of a thorough and uniform mixing of the sample with distilled water in this and all other tests cannot be over-emphasized.'

(4) 'A test to determine when the proper consistency for moulding is reached is made by shaping the sample into a smooth layer about one-half inch thick on the bottom or side of the container. A liquid limit grooving tool is then placed against the bottom of the dish and drawn through the layer of

soil. If the material just flows into and closes the groove at the bottom on its own accord the sample is at the proper consistency for moulding.'

(5) 'The inside walls of the mould should be thinly greased with Vaseline before the specimen is formed, as this will prevent the sample from sticking to the walls of the mould. The material should be worked evenly into the mould and made to fill it completely with a gentle jarring of the mould to assist in the removal of any entrapped air bubbles.'

(6) 'The stainless steel shrinkage gauge may be used to measure the shrinkage directly in percentage.'

(7) 'An investigation by the Highway Laboratory showed that accuracy closer than ± 2 per cent cannot be assured by the bar method.' In other words, if the bar-linear shrinkage is measured to be 20, it may be as low as 19.6 or as high as 20.4.

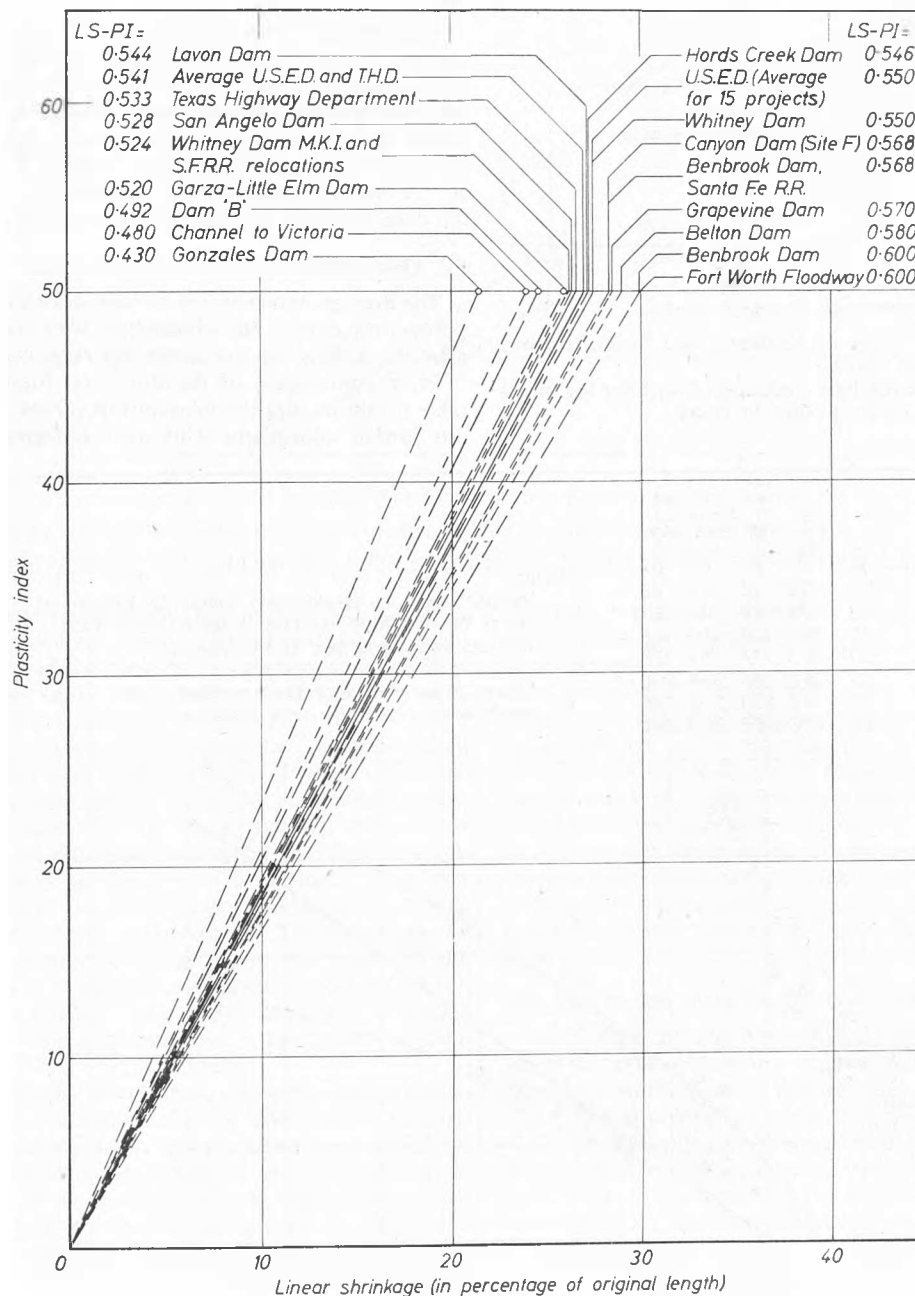


Fig. 2 Summary graph No. 1. Results of study of 14 projects
 Graphique sommaire No. 1. Résultats d'une étude de quatorze projets

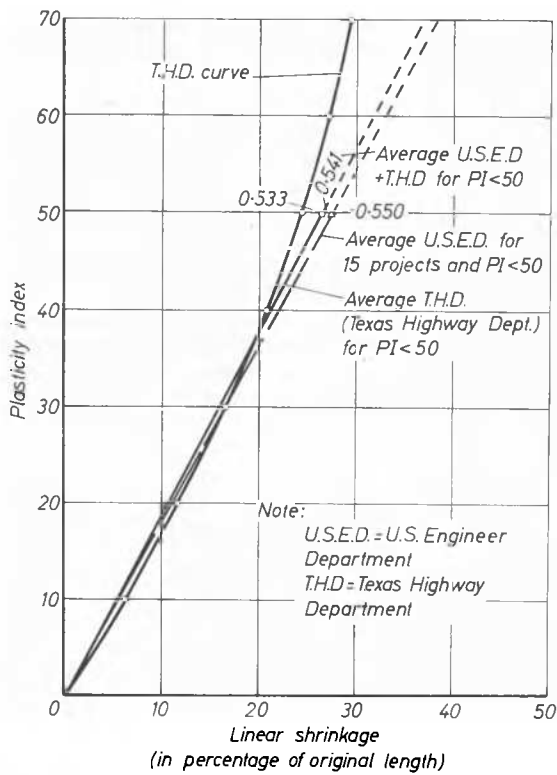


Fig. 3 Comparison of Corps of Engineers and Texas Highway Department test results
 Comparaison des résultats d'essais du Corps des Ingénieurs à ceux du Service des Routes du Texas

'For more accurate results use the method described in the *Standard Method, Texas Highway Department 68.*' This is the volumetric shrinkage method.

To the remarks taken from the *Texas Highway Department Manual* should be added the statement that the moulded specimens are to be air-dried overnight in an air-drier prior to placing them in the drying oven. If this is not done some of the more cohesive specimens have a tendency to 'curl up', making it impossible to measure the shrinkage accurately.

III. Studies Made in Connection with Bar-linear Shrinkage Test Results

In 1950 and 1951 the writer carried out a study on the relationship that appeared to exist between the linear shrinkage and the plasticity index of soils on 15 projects in Texas. The end results of this study are shown in condensed form in Figs. 2 and 3.

Inspired by a stimulating question by Professor A. Casagrande of Harvard University in 1951, the writer extended his studies to include the liquid limit, and to that end a presentation was devised that would show the inter-relationship between liquid limit, plasticity index and bar-linear shrinkage on one sheet and in one plot, and Casagrande's 'A'-line was added to it. A typical example of the presentation is shown in Fig. 4. To date the study includes only nine projects.

IV. Discussions

The average curves in Fig. 4 were drawn through the plotted points only once. No adjustments were made to these curves after the table at the top centre was compiled.

From comparison of the third and fourth columns of the table it follows that the relationship curves can be drawn without further adjustment with such a degree of accuracy that

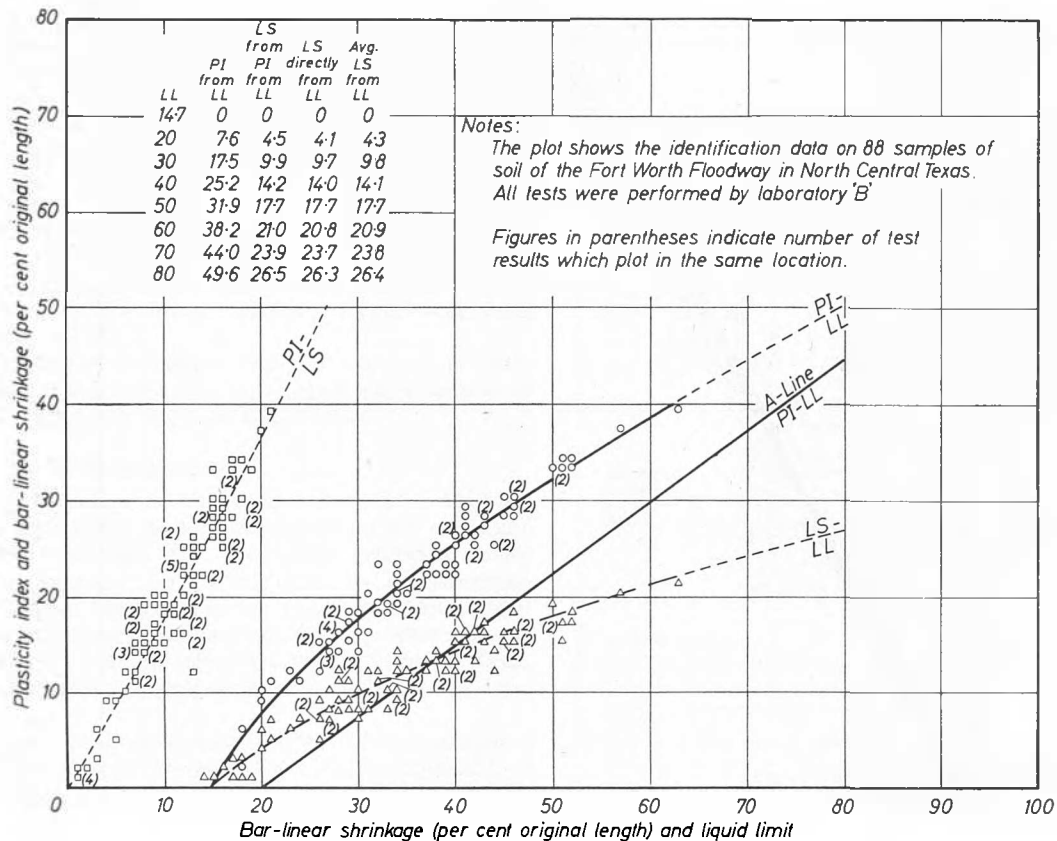


Fig. 4 Typical liquid limit, plasticity index and bar-linear shrinkage relationships (Fort Worth Floodway)
 Relations typiques entre la limite de liquidité, l'indice de plasticité et le retrait linéaire (digues de Fort Worth)

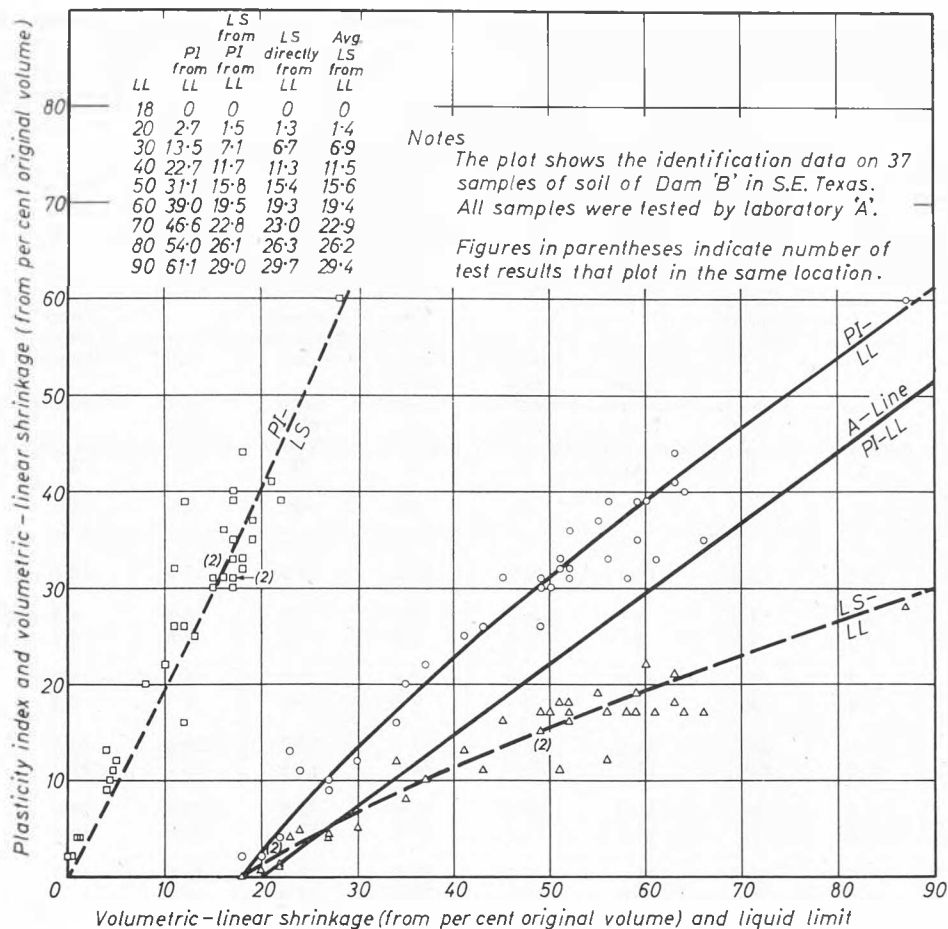


Fig. 5 Liquid limit, plasticity index and volumetric-linear shrinkage relationships, Dam 'B'
Relations entre la limite de liquidité, l'indice de plasticité et le retrait volumétrique-linéaire, Barrage en terre 'B'

deviations of the curves in which the bar-linear shrinkage is involved are, on the average, not in excess of 0.8 of 1 per cent for soils. For some of the projects the average deviation is as small as 0.3 of 1 per cent. The maximum deviation for soils is 1.4 per cent and for 1 caliche, 3.9 per cent.

This manner of presenting the relationships between liquid limit, plasticity index and linear shrinkage has the advantage of possessing at least one definite point for the plasticity index-linear shrinkage relationship, i.e. the origin and at least one quite definite point for the linear shrinkage-liquid limit relationship, namely the point on the axis of abscissae. A further advantage is that all of the relationships can be shown on one sheet without too much interference. Theoretically, the plasticity index-bar-linear shrinkage curve will pass through the origin only if it is assumed that a strictly cohesionless soil will not shrink on drying. The graph presented in Fig. 4 proves this point. The only exception is the graph for Dam 'B', shown in Fig. 5 and discussed below.

Fig. 5 has been included primarily to add to the present knowledge regarding the contention of some investigators that the linear shrinkage as derived from the volumetric-linear shrinkage curve, based on shrinkage expressed in per cent of original volume, would be a more reliable indicator than the bar-linear shrinkage. Judging from the comparison of the third and fourth columns of the table in the top centre of Fig. 5, it would appear that these investigators might be correct. However, the evidence produced by the seven other soil projects proves that there is not sufficient difference in the end results of bar-linear shrinkage relationships curves and one volumetric-linear

shrinkage relationship curve to require that the volumetric-linear shrinkage procedure be used in lieu of the bar-linear shrinkage test.

Incidentally, it is noted that in Fig. 5 the lower end of the PI-LS curve would not pass through the origin if it were drawn as an average curve through the plotted points. This is probably due to the fact that considerable lateral contraction can take place in the soil in a shrinkage cup and that truly linear shrinkage takes place only vertically. This is in the direction of a dimension which is only 30 per cent of the diameter. By involving the comparatively large diameter of the cup in the computed volumetric-linear shrinkage, the value found for this quantity is bound to be lower than it should be.

Va. Conclusions about the Bar-linear Shrinkage Test

Advantages of the bar-linear shrinkage test and the bar-linear shrinkage value over other identification tests and their results are summed up as follows:

- (1) The apparatus has no moving parts.
- (2) Of most soil tests developed to date it is probably one that is least affected by the human equation.
- (3) Wear of the apparatus has to be very considerable before it will affect the test results, and wear in the direction of the bar is extremely slow.
- (4) Six samples can be tested in the apparatus almost simultaneously. This is important, particularly on large construction projects.
- (5) The apparatus is easily cleansed.

Table

Showing summary on liquid limit, plasticity index and linear shrinkage relationships as derived from tests on 1664 samples of soil and 41 samples of caliche taken for Seven Dam and two Floodway Corps of Engineers Projects in Texas

Tableau indiquant sommairement les relations entre limite de liquidité, indice de plasticité et retrait linéaire, trouvées lors des essais de 1-664 échantillons de sols et 41 échantillons de caliche, prélevés sur sept barrages et deux digues, étudiés par le Corps des Ingénieurs du Texas

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|-----------------------|----------------|--------------------|-----------------------|-----------------------|-----------------------|---------------------|----------------------|-------------------|-------------------|----------|
| Name of project | San Angelo Dam | Hords Creek Dam | Canyon Dam | Belton Dam | Fort Worth Floodway | Dallas Floodway | Garza-Little Elm Dam | McGee Bend Dam | Dam 'B' | |
| Location in Texas: | West Texas | West Central Texas | South Texas | Central Texas | North Central Texas | North Central Texas | North Texas | South East Texas | South East Texas | |
| Geological system: | Permian | Permian | Cretaceous Comanchean | Cretaceous Comanchean | Cretaceous Comanchean | Cretaceous Gulf | Cretaceous Gulf | Tertiary Pliocene | Tertiary Pliocene | |
| Geological series: | | | | | | | | | | |
| Geological formation: | Clear Fork | Wichita | Fredericksburg | Fredericksburg | Washita | Eagle Ford | Eagle Ford | Citronelle | Citronelle | |
| Testing Laboratory: | Laboratory 'A' | Laboratory 'A' | Laboratory 'A' | Laboratory 'A' | Laboratory 'B' | Laboratory 'B' | Laboratory 'B' | Laboratory 'B' | Laboratory 'A' | Averages |
| Number of samples: | 41 | 48 | 1087 | 32 | 88 | 58 | 246 | 68 | 37 | 189 |
| LL for PI = LS = 0: | 15.0 | 16.0 | 18.0 | 14.0 | 14.7 | 14.5 | 17.0 | 18.0 | 18.0 | 16.1 |
| PI for LL = 20: | 6.2 | 5.8 | 4.5 | 6.4 | 7.6 | 7.9 | 5.5 | 4.3 | 2.7 | 5.7 |
| LS for LL = 20: | 3.4 | 3.3 | 2.7 | 4.3 | 4.3 | 4.2 | 3.5 | 2.4 | 1.4 | 3.3 |
| PI for LL = 30: | 16.3 | 16.6 | 16.4 | 15.0 | 17.5 | 17.7 | 15.3 | 15.8 | 13.5 | 16.0 |
| LS for LL = 30: | 8.4 | 9.5 | 9.6 | 9.5 | 9.8 | 9.6 | 9.7 | 8.4 | 6.9 | 9.0 |
| PI for LL = 40: | 24.9 | 25.2 | 24.4 | 22.4 | 25.2 | 25.7 | 22.5 | 23.5 | 22.7 | 24.1 |
| LS for LL = 40: | 12.4 | 14.2 | 13.9 | 13.7 | 14.1 | 13.8 | 13.5 | 12.2 | 11.5 | 13.3 |
| PI for LL = 50: | 32.8 | 33.0 | 31.0 | 29.1 | 31.9 | 32.7 | 29.6 | 29.8 | 31.1 | 31.2 |
| LS for LL = 50: | 15.6 | 18.4 | 17.2 | 17.4 | 17.7 | 17.2 | 16.6 | 15.2 | 15.6 | 16.8 |
| PI for LL = 60: | 40.3 | 40.2 | 36.8 | 35.3 | 38.2 | 38.9 | 36.8 | 35.3 | 39.0 | 37.9 |
| LS for LL = 60: | 18.6 | 21.9 | 19.8 | 20.6 | 20.9 | 19.9 | 18.9 | 17.7 | 19.4 | 19.7 |
| PI for LL = 70: | 47.5 | 47.1 | 42.3 | 41.3 | 44.0 | 44.6 | 43.9 | 40.3 | 46.6 | 44.2 |
| LS for LL = 70: | 21.1 | 25.2 | 22.0 | 23.6 | 23.8 | 22.0 | 20.6 | 19.8 | 22.9 | 22.3 |
| PI for LL = 80: | 54.6 | 53.8 | 47.4 | 47.2 | 49.6 | 49.7 | 51.0 | 45.2 | 54.0 | 50.3 |
| LS for LL = 80: | 23.4 | 28.1 | 24.0 | 26.5 | 26.4 | 23.6 | 21.7 | 21.8 | 26.2 | 24.6 |

(6) The numerical value of the bar-linear shrinkage has the advantage of not having been obtained by subtraction of two values which may differ in magnitude by as much as 400 per cent on a percentage basis. Both of these values could be in error due to many causes which cannot possibly be continuously avoided and each one of a pair of these values could be in error in the opposite direction.

(7) By using a special rule for measuring the length of the shrunk test specimen, no computations are needed to arrive at the bar-linear shrinkage value. Consequently no error can be made in the computations and no checking of computations is required. The operator has only to read the rule twice, once before and once after recording.

(8) The cost of the bar-linear shrinkage test is less than 20 per cent of the cost of the plasticity index test.

Vb. Conclusions from Bar-linear Shrinkage Studies

(1) The use of the bar-linear shrinkage as an identifier of soils is fully justified and may even be less approximate than the use of the plasticity index for identification purposes of all moderately cohesive soils (liquid limit 14 ± to 60 ±, plasticity index 0 ± to 40 ±).

(2) It cannot be denied that quite definite relationships exist between the bar-linear shrinkage and the Atterberg limit values of soils (Table and Fig. 6). A less definite relationship exists between the bar-linear shrinkage and the Atterberg limit values of caliches but simultaneously the relationship between the

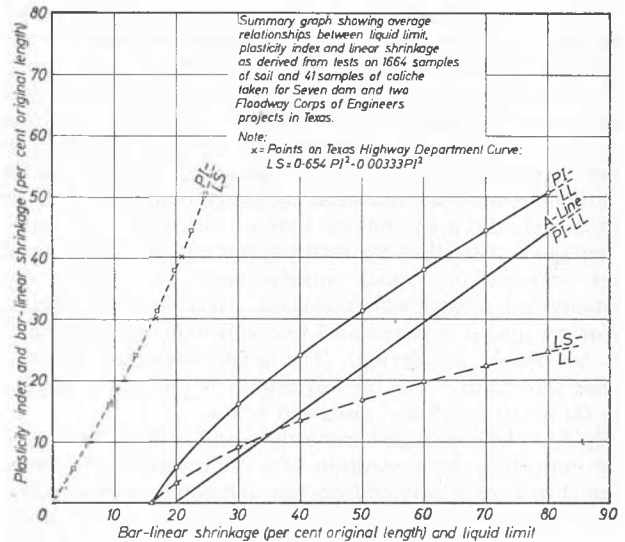


Fig. 6 Summary graph No. 2. Results of study of nine projects and comparison of Corps of Engineers and Texas Highway Department test results

Graphique No. 2, résumant les résultats d'essais, d'une étude de neuf projets, et comparaison des résultats obtenus par le Corps des Ingénieurs à ceux obtenus par le Service des Routes du Texas

liquid limits and the plasticity indices of caliches is also less definite (see Table and Fig. 6).

(3) From the investigation carried out to date the writer concludes: that the relationship between the bar-linear shrinkage and the liquid limit is only slightly less definite than the relationship between the bar-linear shrinkage and the plasticity index values, at least for the soils found in Texas; is inclined to

believe that, for soils with a plasticity index of less than about 6, the bar-linear shrinkage test may be a better indicator of the plasticity than the plasticity index test; and is also of the opinion that irregularities in the LS-PI relationship in this range may be due more to uncertainties in the plasticity index determinations than to uncertainties in the bar-linear shrinkage determinations.