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A method for determining the strength parameters of soils, presented at 52d Annual Meeting of Highway Research Board, January 1973

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A METHOD FOR DETERMINING THE STRENGTH PARAMETERS OF SOILS

by

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ABSTRACT

A simple method for determining the cohesion, c, and internal friction angle, ϕ, of soils and stabilized materials requiring knowledge of only the unconfined compressive strength and tensile strength is presented. The tensile strength may be conveniently determined by the newly developed double-punch test. A procedure for establishing c and ϕ from the Mohr-Coulomb failure envelope constructed using the proposed method is outlined. Comparisons showing good agreement between strength parameters calculated from the proposed method and from those measured by more conventional direct shear and split-tensile strength tests for various types of soils are given.

INTRODUCTION

Conventional analyses of the stability of soil-pavement systems require knowledge of one or more of the strength parameters cohesion, c; internal friction angle, ϕ; unconfined compressive strength, q_u; and tensile strength, σ_t. Commonly used methods for establishing c and ϕ include direct and triaxial shear tests. These test methods are generally time-consuming and expensive and are particularly poorly suited to testing stabilized pavement material because of the large particle sizes and high strengths involved. This frequently necessitates the use of large test specimens resulting in the need for larger test equipment and higher test loads.

This paper presents a simple method for determining the (undrained) cohesion and internal friction angle of soils and stabilized materials if the tensile and compressive strength of the material are known. The compressive strength can be determined conventionally and the tensile strength may be simply established using the newly developed double-punch test[7,8]. A comparison of loading conditions, types of failure planes, and failure envelopes for the direct shear, triaxial, and proposed method is given in Fig. 1.

The method assumes that the cohesion may be adequately expressed as a function of soil type and tensile strength. Both graphical and analytical methods of establishing c and ϕ are given. Comparisons between strength parameters calculated from the proposed method and those measured by more conventional direct shear and split-tensile strength tests are presented and discussed.

THEORETICAL CONSIDERATIONS

The modified Mohr-Coulomb's failure envelope used in this paper has been suggested by Chen and Drucker[(3)]. The failure envelope (Fig. 2) is denoted by AG'H where AG' is part of the circle and G'H is a straight line. The distance AB is equal to the magnitude of the tensile strength. BE is equal to the radius of the unconfined compressive strength Mohr circle and distance BG is equal to the cohesion. The internal friction angle ϕ is the slope of the line GH.

In order to establish the failure envelope, at least three points on the envelope should be given. AB can be determined from a simple indirect tensile test such as the double-punch test. Distance BF is equal to the compressive strength and may be determined by a conventional unconfined compression test.

The above information provides two of the three points necessary to define the envelope. The third point can be determined by noting that experimental data indicates the cohesion, c, is related to the tensile strength of the material (see Fig. 5). From Fig. 2, the unconfined compressive strength can be computed by:

$$q_u = 2\ c\ \tan(45° + \frac{\phi}{2}) \qquad (1)$$

in which

c = cohesion

ϕ = internal friction angle

q_u = unconfined compressive strength

Rearranging Eq. (1) we have

$$\phi = 2 \tan^{-1} \frac{q_u}{c} - \frac{\pi}{4} \ (\text{where } \phi < \frac{\pi}{2}) \qquad (2)$$

If $\xi = \frac{\sigma_t}{c}$

then $c = \frac{\sigma_t}{\xi}$. (3)

where ξ is the ratio of tensile strength to cohesion. It will be shown later that ξ can be determined experimentally and is a function of plasticity index[10,11,13]. Therefore, ϕ may be calculated by Eq. (2) or graphically by connecting points G and H as shown in Fig. 2.

For establishing the failure envelope, the curve distance AG' should be known, since AG' is part of the circle whose center is D and whose radius is R. The radius may be determined by the following formula[3]:

$$R = \frac{q_u}{2} - \frac{\sigma_t \sin\phi}{1-\sin\phi} \tag{4}$$

The circle shown in Fig. 2 must pass through point A and be tangent to the GH line at point G'. AG'H, therefore, represents the failure envelope of the material.

EXPERIMENTAL ANALYSIS

From the preceding discussion, it has been suggested that to determine the cohesion and internal friction angle for soils, two tests, namely the double-punch and unconfined compression tests must be performed. In addition the plasticity index of the material is required.

The double-punch test may be briefly described as follows: using two steel discs (punch) centered on both top and bottom surfaces of a cylindrical soil specimen, the vertical load is applied on the discs until the specimen reaches failure. The tensile strength of the specimen can be calculated from the maximum load by the formula:

$$\sigma_t = \frac{P}{\pi(KbH-a^2)} \quad (5)$$

in which

σ_t = tensile strength

P = load at failure

b = radius of the specimen

H = height of the specimen

a = radius of disc

K = constant (see Table 1)

Table 1 Recommended Values of K

	K Value	
	Soil	Stabilized Materials
Proctor Mold 4"x4.6"	1.0	1.2
CBR Mold 6"x7"	0.8	1.0

The effect of sample-punch size and rate of strain on the results of tensile strength tests have been studied by Fang and Chen[(8)]. They have concluded that a height-to-diameter ratio of the specimen varying from 0.8 to 1.2, and a ratio of the diameter of the specimen to the diameter of the disc varying from 0.2 to 0.3, are suitable for the test.

The rate of strain used for the double-punch test is the ASTM[1] loading rate for unconfined compression tests.

For the unconfined compression test, the same size of specimen is used as for the tensile strength test. A 4"x4.6" Proctor mold was employed in the tests reported herein. The test procedure follows ASTM D-2116[1].

TEST RESULTS AND DISCUSSIONS

The validity of tensile strength determined by the double-punch test has been confirmed by the split-tensile test. It has proved to be a simple and reliable test[6,7,8,9]. Figure 3 shows a comparison of the tensile strength of soils and other materials determined by double-punch and split-tensile tests. These materials include concrete[4,5], mortar, bitumen and cement treated base[8], and rock[6]. Good agreement between both tensile strength results is observed. Figure 4 shows the tensile strength vs. soil type as reflected by the plasticity index. It can be seen that the tensile strength increases as plasticity index increases. Similar conclusions were drawn by Narian and Rawat[12].

It has been found experimentally that cohesion, c, is related to the tensile strength. For rocks it is found that cohesion is equal to two times the tensile strength[10]. For soils it is shown that the relationship between cohesion and tensile strength varies with soil type[11,13]. Figure 5 shows the tensile strength-cohesion ratio vs. plasticity index (P.I.). The following equation expresses the linear relationship shown in Fig. 5:

$$\xi = 0.34 + 0.01\ \text{P.I.} \qquad (6)$$

If the plasticity index is known, ξ can be determined from Eq. 6 and the cohesion, c, can be determined from Eq. 3.

Comparisons between c and ϕ measured in direct shear tests[2] and computed from Eqs. 2 and 3 are shown in Figs. 6 and 7. Good agreement is observed for both values.

SUMMARY AND CONCLUSIONS

1. A simple method for determining the undrained strength parameters, c and ϕ, of soils and stabilized materials from the tensile strength and unconfined compressive strength has been presented. The ϕ and c values can be determined from Eqs. 2 and 3 or graphically from Fig. 2. The ξ value can be found from Eq. 6 if the plasticity index of the material is known.

2. The unconfined compression and double-punch tests are both simple and easy tests to perform. No additional equipment is needed and the tests can be conveniently

performed in conjunction with routine CBR and compaction tests.

3. The proposed method for determining c and Ø can save up to two thirds of the time necessary for conventional direct shear and triaxial shear tests.

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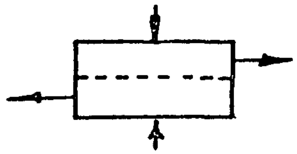
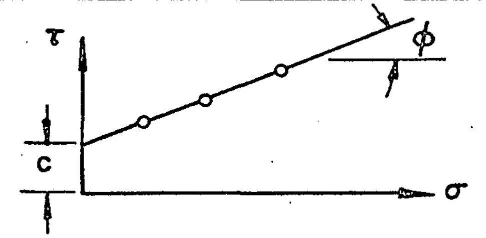
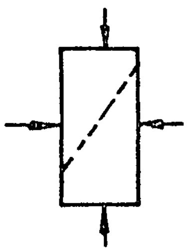
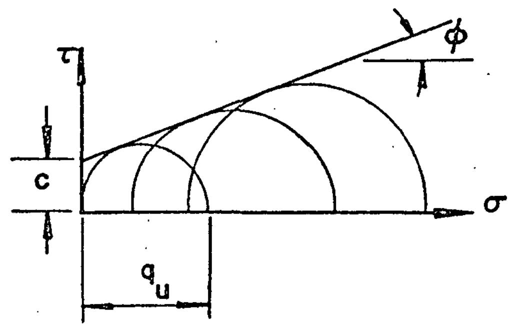
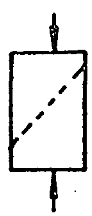
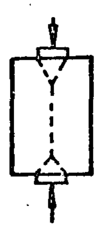
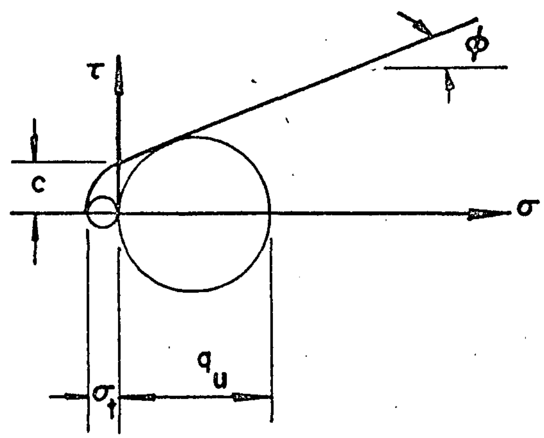
Fig. 1 Comparisons of Various Features for Direct Shear, Triaxial, and Proposed Methods

Type of Test	Loading Conditions and Type of Failure Plane	Failure Envelope and Strength Parameters	Min. No. of Specimens Required	Strength Parameters Obtained from the Test
Direct Shear			3	c, ϕ
Triaxial Test			3	c, ϕ, q_u
Proposed Method	Unconfined Compression Test  Tensile (Double Punch) Test 		1 1	c, ϕ, q_u, σ_t

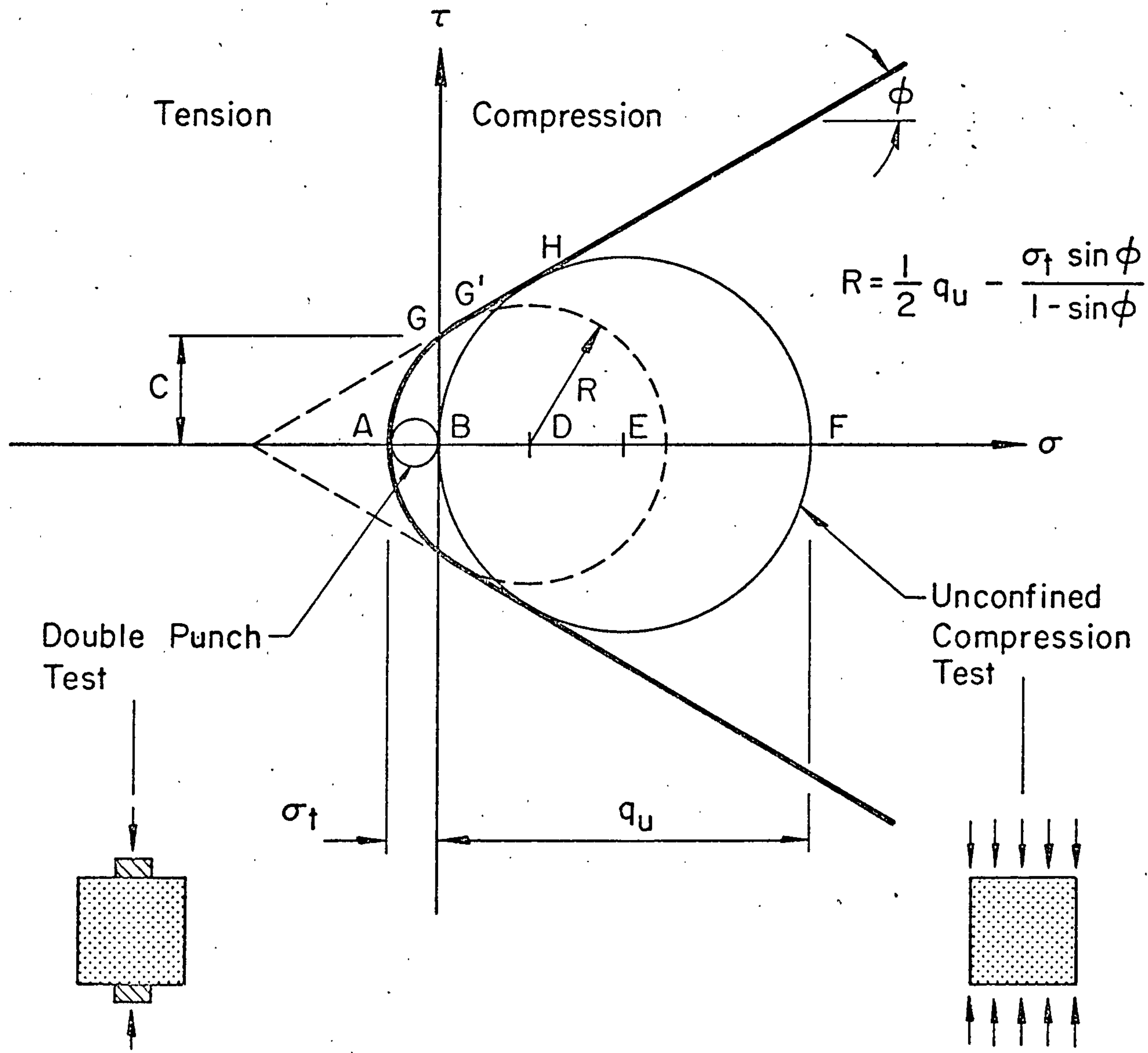


Fig. 2 Modified Mohr-Coulomb Criterion

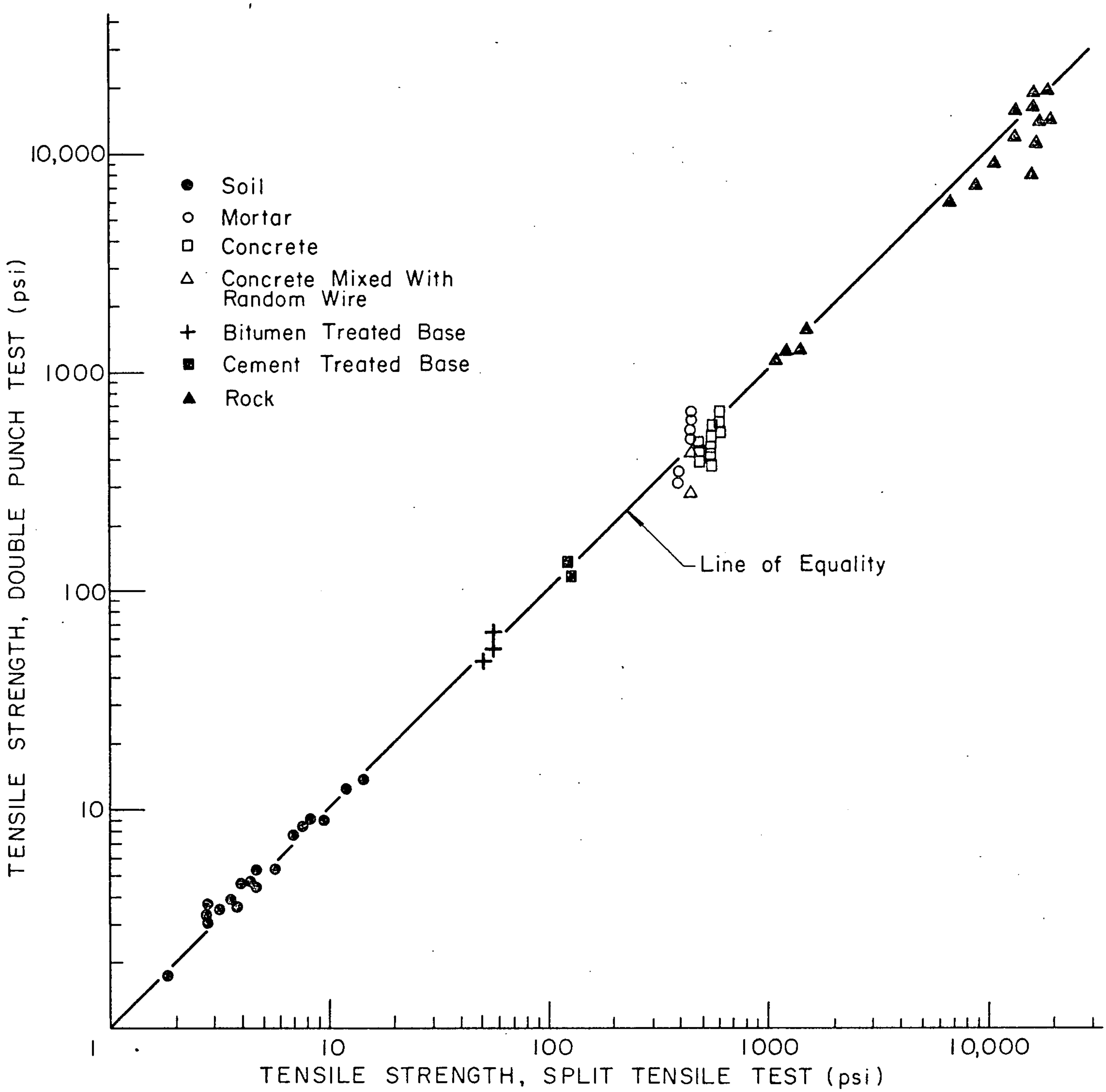


Fig. 3 Comparison of Tensile Strength of Various Materials Determined by Double Punch and Split Tensile Tests

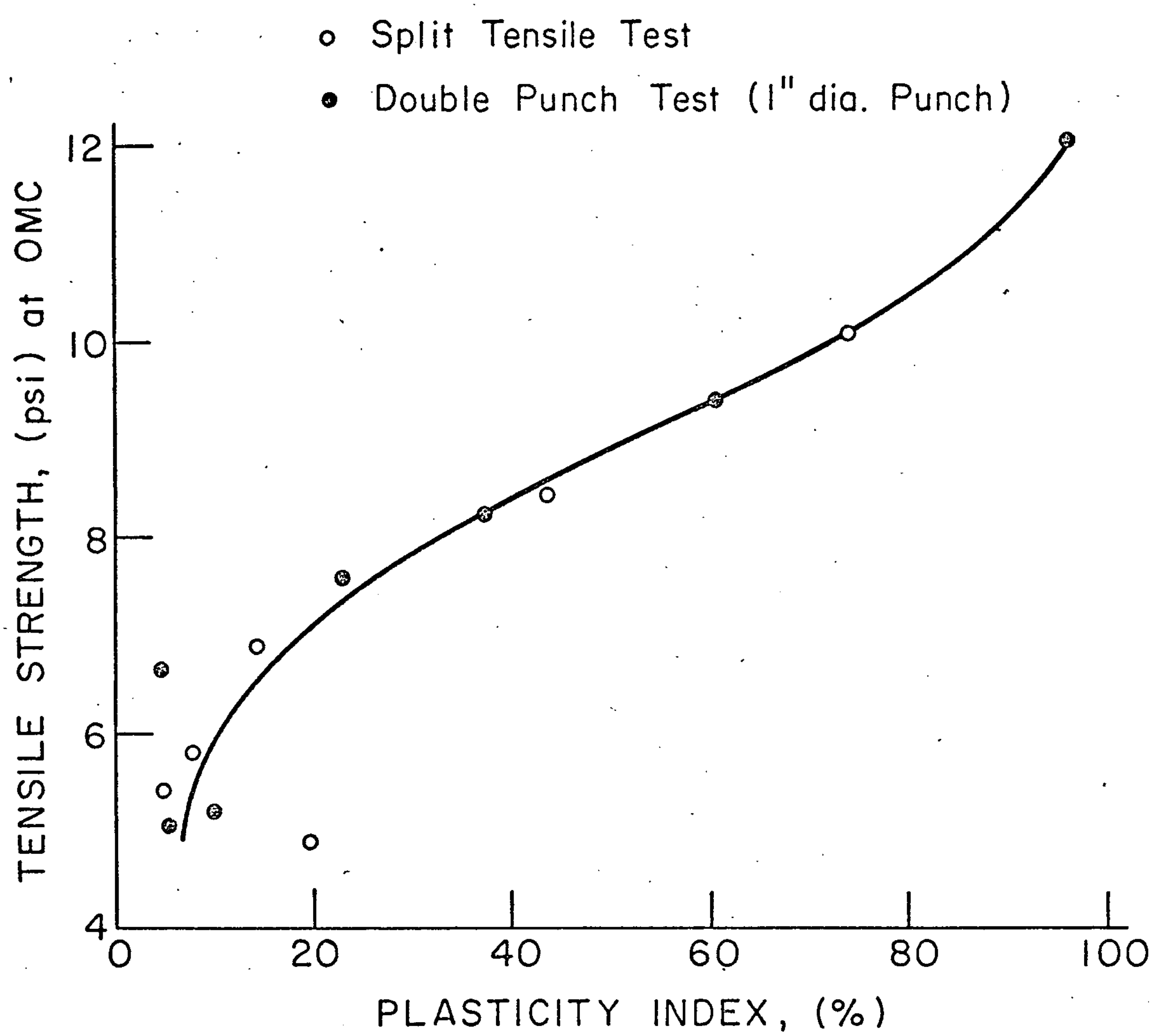


Fig. 4 Relationships between Tensile Strength and Plasticity Index

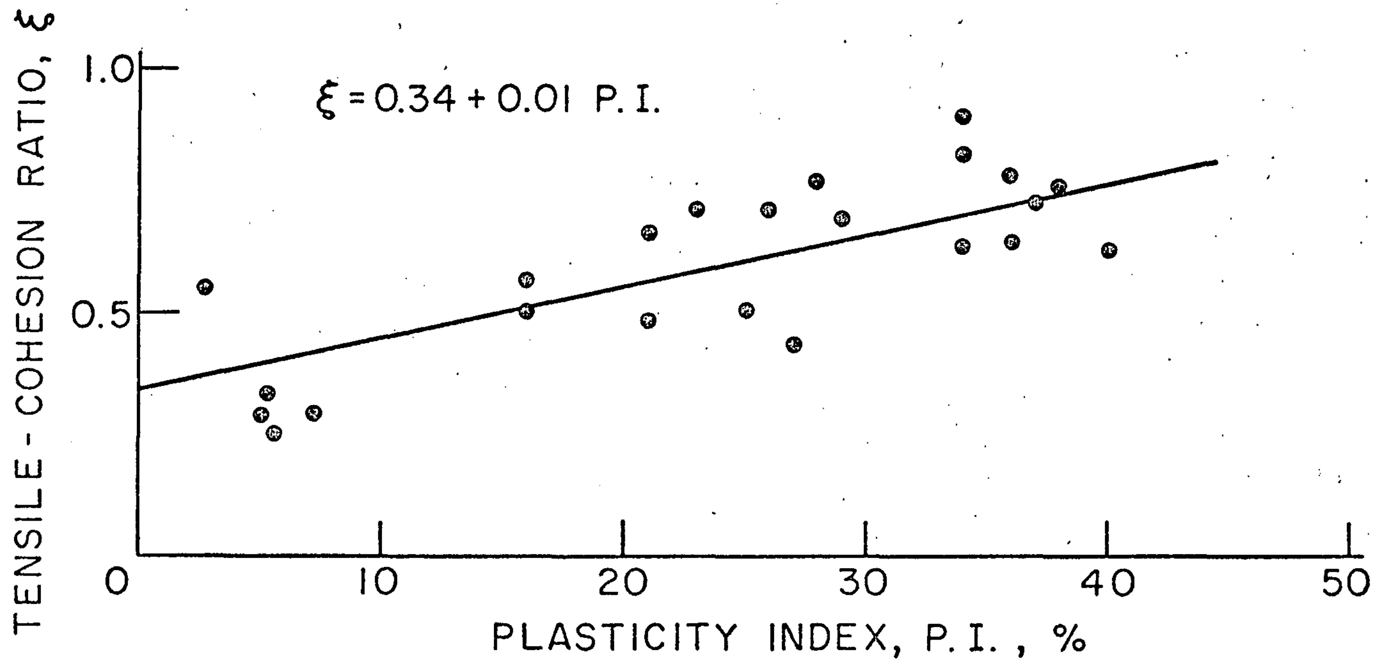


Fig. 5 Tensile Strength-Cohesion Ratio Versus Plasticity Index

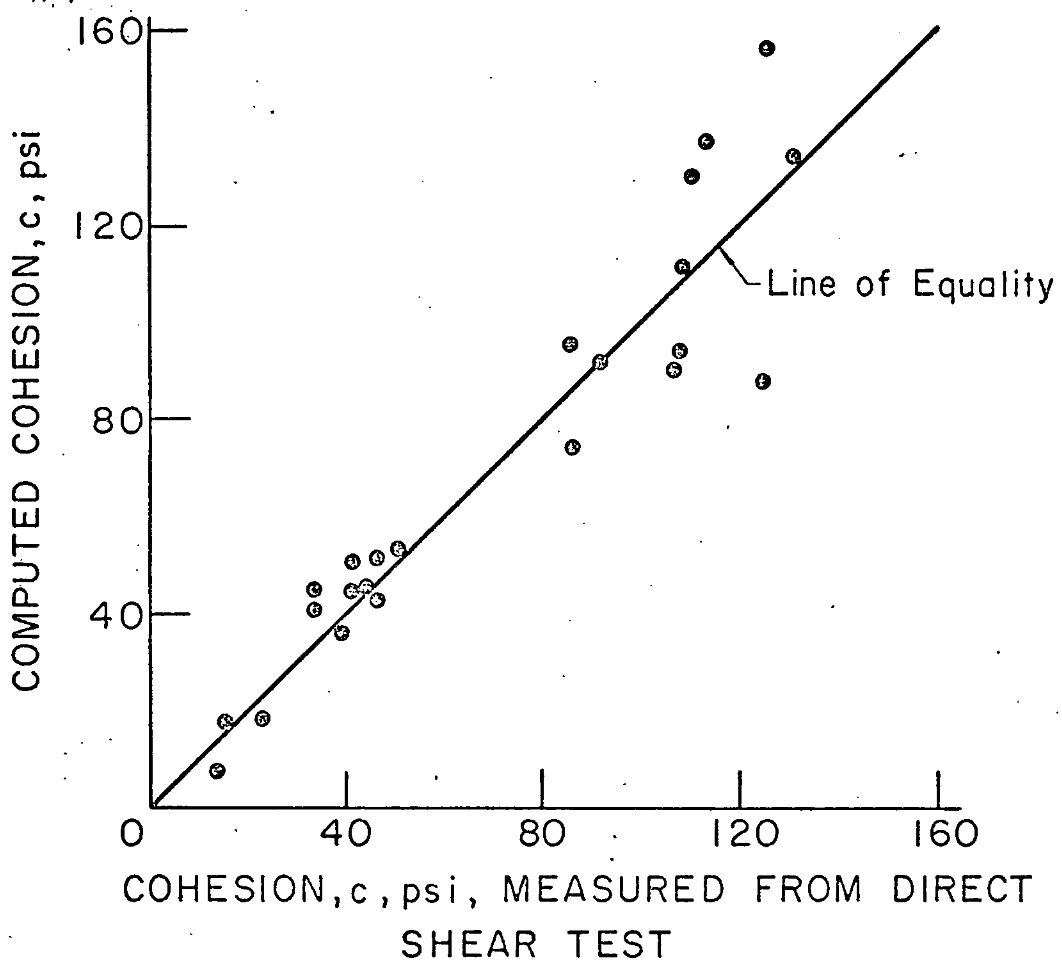


Fig. 6 Comparison of Cohesion, c by Proposed Method and Direct Shear Test

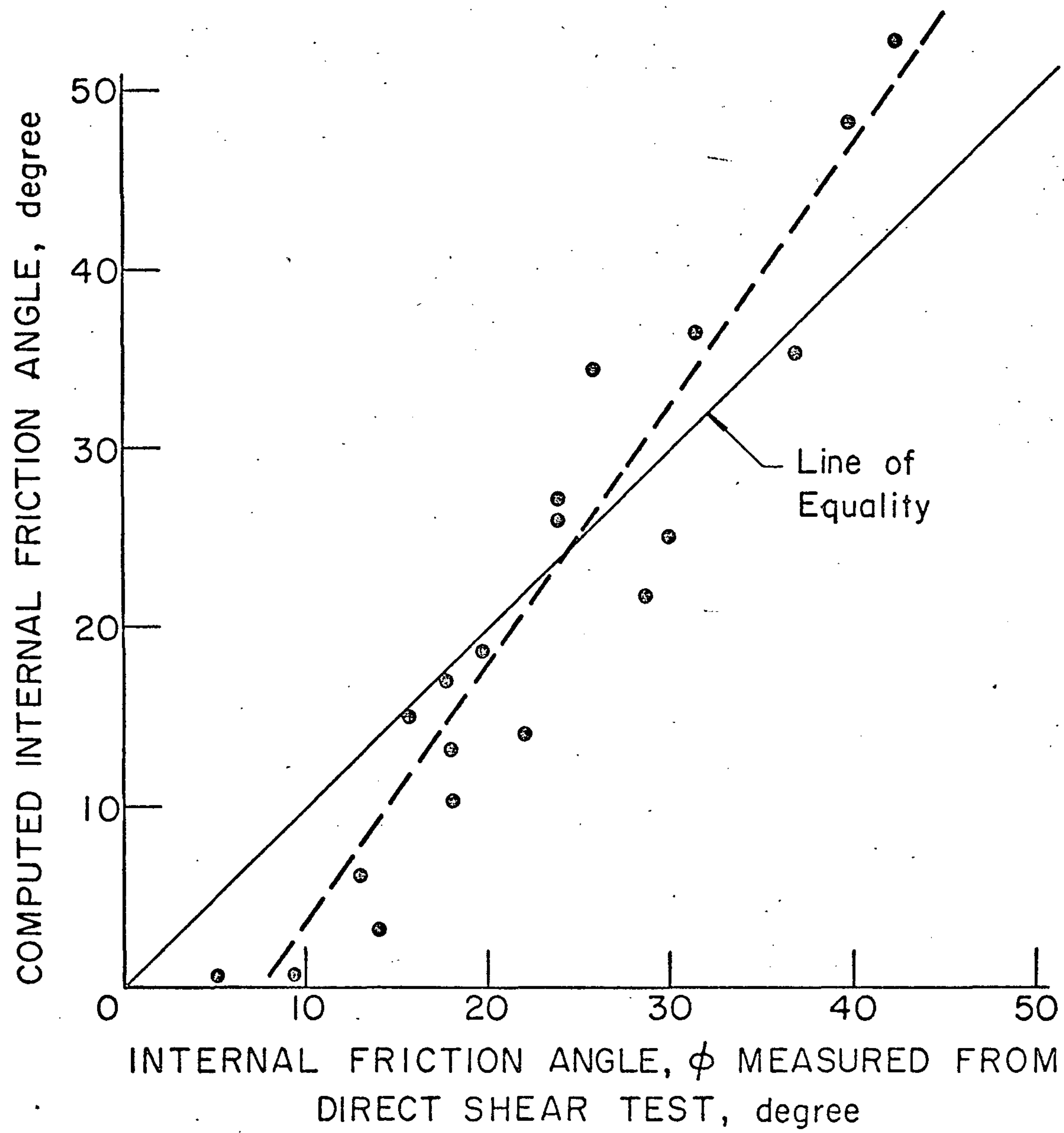


Fig. 7 Comparison of Internal Friction Angle, ϕ by Proposed Method and Direct Shear Test