1970

Method of test for tensile strength of soil, rock and stabilized materials by double punch test, July 1970

H. Y. Fang

Method of Test for Tensile Strength of Soil, Rock and Stabilized Materials by Double Punch Test

1. Scope

This report covers test procedures for the determination of the tensile strength of soil, rock and stabilized materials in undisturbed and remolded conditions.

2. Apparatus

a. Mold

The mold shall be cylindrical in shape, made of metal and having the dimensions indicated in items (1) and (2) below. They shall have a detachable collar assembly approximately 2 1/2" in height, to permit preparation of compacted specimens of the desired height and volume. The mold may be of the split type, consisting of two half-round sections or a section of pipe split along one element, which can be securely locked in place to form a cylinder as described above. The mold and collar assemble shall be so constructed that it can be fastened firmly to a detachable base plate. Capacity and dimensions of the mold shall be as follows:

(1) Proctor mold; having an internal diameter of 4.0 in. and a height of 4.6 in. and a volume of 1/30 cu. ft.

(2) CRB mold; having an internal diameter of 6.0 in. and a height of 7.0 in. with a circular steel spacer disc 5 15/16 in. in diameter and 1 in. in height.

b. Steel Punch

(1) Two steel punches, with a diameter of 1 in. and a thickness of 3/4 in. used with 4.0 in. diameter specimen.

(2) Two steel punches, with a diameter of 1.33 in. (CBR piston) and a thickness of 3/4 in. used with 6 in. diameter specimen.

c. Laoding Machine

The loading machine will have a compressive device, and it may be a platform weighing scale equipped with a screw-jack-activated load yoke, a dead-weight load apparatus, a hydraulic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading of 2-inches per minute. This loading machine is the same used in "The Unconfined Compressive Strength of Cohesive Soil, ASTM D 2166-66." [1] (See Fig. 1).

d. Tamper

(1) A metal tamper, using 5.5 lb. rammer and 12 in. drop.

(2) A metal tamper, using a 10 lb. rammer and 18 in. drop.

The tamper will be a metal tamper either manually operated, mechanically or automatically operated, or any other tamper that provides the compactive effort to that obtained by the comparable tampers mentioned in d (1) and d (2), respectively.

e. Sample Ejector

The sample ejector shall be capable of ejecting the soil core from the sampling tube or mold in the same direction of travel as the sample entered the tube or mold and with negligible disturbance of the sample. Conditions at the time of sample removal may dictate the directions of removal, but the principal concern is to keep the degree of disturbance negligible.

f. Deformation Indicator

The deformation indicator shall be a dial indicator graduated to 0.001 in. and having a travel range of at least 20 per cent of the length of the test specimen or other measuring device meeting this requirement.

g. Drying Oven

A thermostatically controlled drying oven capable of maintaining a temperature of 230F° (110C°) for drying moisture content samples.

h. Balances

The balances shall be suitable for weighing soil specimens. Specimens of less that 100g shall be weighed to the nearest 0.01g, whereas, specimens of 100g or larger shall be weighed to the nearest 0.1g.

i. Miscellaneous Apparatus

Other general apparatus such as a mixing bowl, straightedge, scales, specimen trimming, carving tools, remolding apparatus, moisture content cans, etc.

3. <u>Preparation of Test Specimens</u>

(a) Specimen size is related with the diameter of the disc (see 2-b). It will be such that the ratio of height-to-diameter of the specimen varies from 0.8 to 1.2, and the ratio of diameter of specimen to the diameter of the disc varies from 0.2 to 0.3. For more convenience and practical manner specimen size of the Proctor mold (4" x 4.6") or the CBR mold (6" x 6") with a 1" steel spacer disc which are described in section 2 (a) should be used.

(b) For Soil

(1) Undisturbed Specimen

For preparing undisturbed specimen will follow the same practice that "Unconfined

Compressive Strength of Cohesive Soil" test follows ASTM designation D 2166-66.

(2) Remolded Specimen

The remolded specimen for soils will be obtained either from a CBR mold with a circular metal spacer disc 5 5/16 in. in diameter and 1 in. in height or from a Proctor mold that are described in section 2 (a) and using the same practice that follows in ASTM designation, D 1883-67 or D 698-66T, respectively.

(c) For Rocks

Specimens are obtained in the same form as in the "Diamond Core Drilling for Site Investigation." ASTM Designation, D 2113-62T method is used, and the size recommended is 4" x 4" cylinder specimen.

(d) For Bituminous Concrete

Bituminous specimen is obtained from the field core sample in the same form as rock, or made from the laboratory mix design (ASTM Designation D 1559-65). The most important concern here is that temperature of the sample should be recorded either from the field specimen or from the lab. A 4" x 4" specimen site is recommended.

(e) For Concrete

The effect of the sample size and the dimension of the punch have been studied by Hyland and Chen.*[2] Based on the test of concrete and mortar, they have found that the effect of height-to-diameter ratio and punch size on the tensile strength is approximately a linear relation, and Chen*[3] recommends that size of the specimens will be such that the ratios between diameter of the specimen-to-diameter of the punch, and height of the specimen-to-diameter of the punch, will be a value no greater than 4, for more convenient and practical manner a 6" x 12" cylinder specimen is recommended.

4. <u>Test Procedure</u>

(a) Place the specimen in the loading device so that it is centered on the bottom punch. Adjust the loading device carefully so that the upper punch just makes contact with the specimen. Zero the deformation indicator. Load is applied slowly to produce axial strain at a rate of 1/2 to 2 per cent per minute and record load and deformation values every 30 seconds. Regulate the rate of strain so that the approximate time to failure for unsealed specimens never exceeds 10 minutes. This means that softer materials which will exibit larger deformations at failure should be tested at a higher rate of strain. Conversely, stiff or brittle materials which exhibit small deformations at failure should be tested at a lower rate of strain. Continue loading until the load values decrease with increasing strain, or until 20 per cent strain is reached. Continue following the same practice that is followed in the unconfined compressive strength of cohesive soil.

(b) Coinside the upper punch with the lower punch to be sure that the load will be acting in the symmetrical axis of both punches, since the lower punch is movable on the lower platen of the load device. This operation will be easy to perform. Find the center of both the top and bottom surfaces. By this center, draw a circle of the same diameter of the punch that will be used, then place the specimen on the load device coinsiding the circles on both the top and bottom surfaces with each punch respectively.

(c) Make a sketch of the test specimen at failure showing the pattern of the crack, especially the cracking pattern at top and bottom surfaces of the specimen (see Fig. 2).

5. Calculation

Tensile strength σ_t may be computed from the following equation:

$$\sigma_t = \frac{P}{\pi (K b H - a^2)}$$

where:

P = applied load, lbs.

2a = steel disc diameter, inch.

2b = specimen diameter, inch.

H = height of specimen, inch.

K = constant

For soil, K = 1

For mortar, concrete, rock and bituminous concrete,

K = 1.2

Derivation of the above equation, is shown in the Appendix A.

6. <u>Report</u>

The report shall include the following:

a. Tensile Strength

b. Type and shape of specimen:

Undisturbed

Remolded

Height-to-diameter ratio

c. Visual description:

Soil name, symbol, etc.

d. Initial density, moisture and degree of saturation

e. Average strain at failure, per cent

f. Average rate of strain to failure, per cent

g. For concrete, the water-cement ratio, type of cement and maximum aggregate size should be included. For bituminous concrete, the asphalt content, maximum aggregate size and the temperature of specimen should be recorded and for rock, the types and geological formation of rock should be recorded also.

h. Remarks: note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained.

i. Mode of failure should be sketched. (see Fig. 2 and 3).

TENSILE STRENGTH TEST (Double Punch Test)

Project ______________________ Job No. ______________________

Location of Project ____

Description of Soil ____

Tested by ______________________ Date of Testing ______________________

Sample Data

Diam. ____________ in. Area A_o ____________ in^2 Ht. L_o ____________ in.

Vol. ____________ in^3 wt. ____________ lb. Wet unit wt. ________ pcf.

Water Content ________ % Dry unit wt. ________ pcf. Disc(punch)diam. ______ in.

Deformation dial reading	Load dial	Sample Deformation ΔL in.	Unit Strain $\Delta L/L_o$	Total Load on Sample (Col.2.LRC)	Sample Unit Load
1	2	3	4	5	6

Tensile strength σ_t = ______________

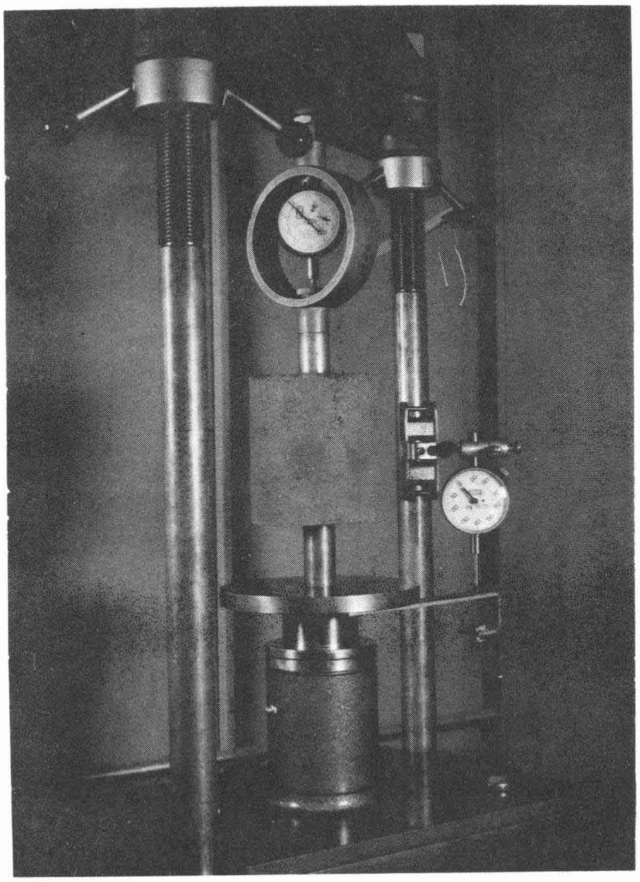

Fig. 1

Double Punch Test Setup

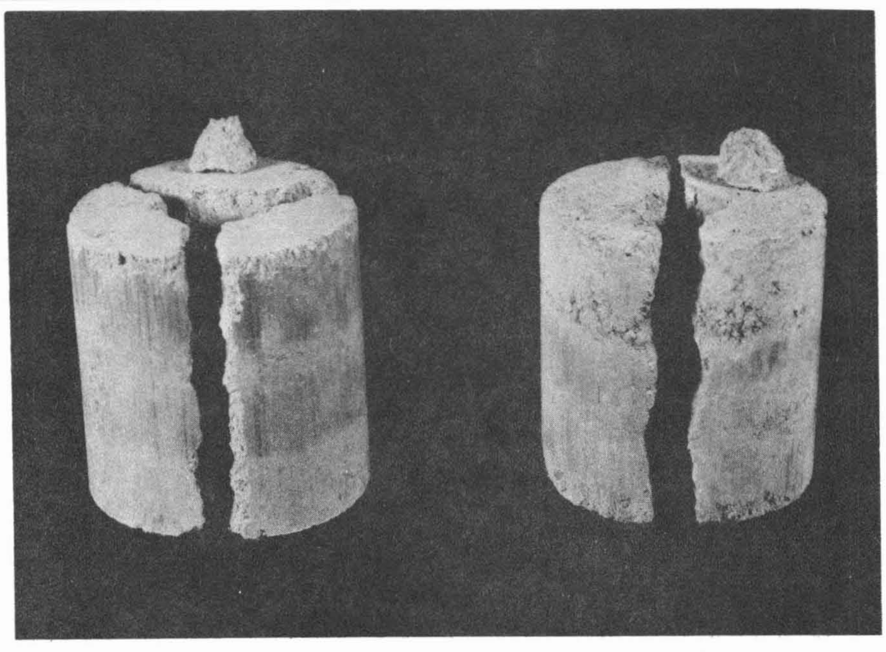

Fig. 2

Modes of Failure of Soil

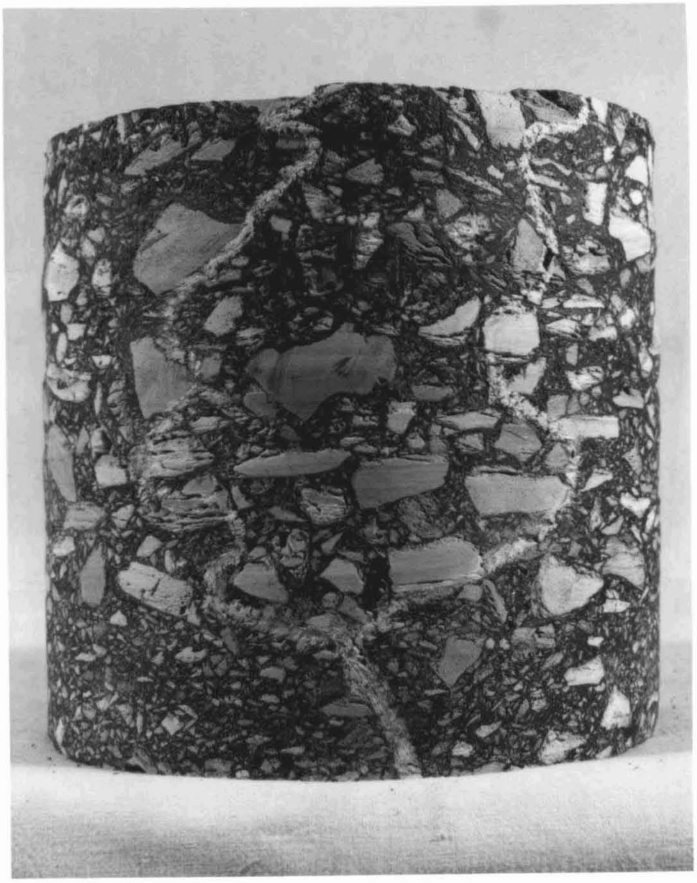

Fig. 3

Modes of Failure of Bituminous Concrete

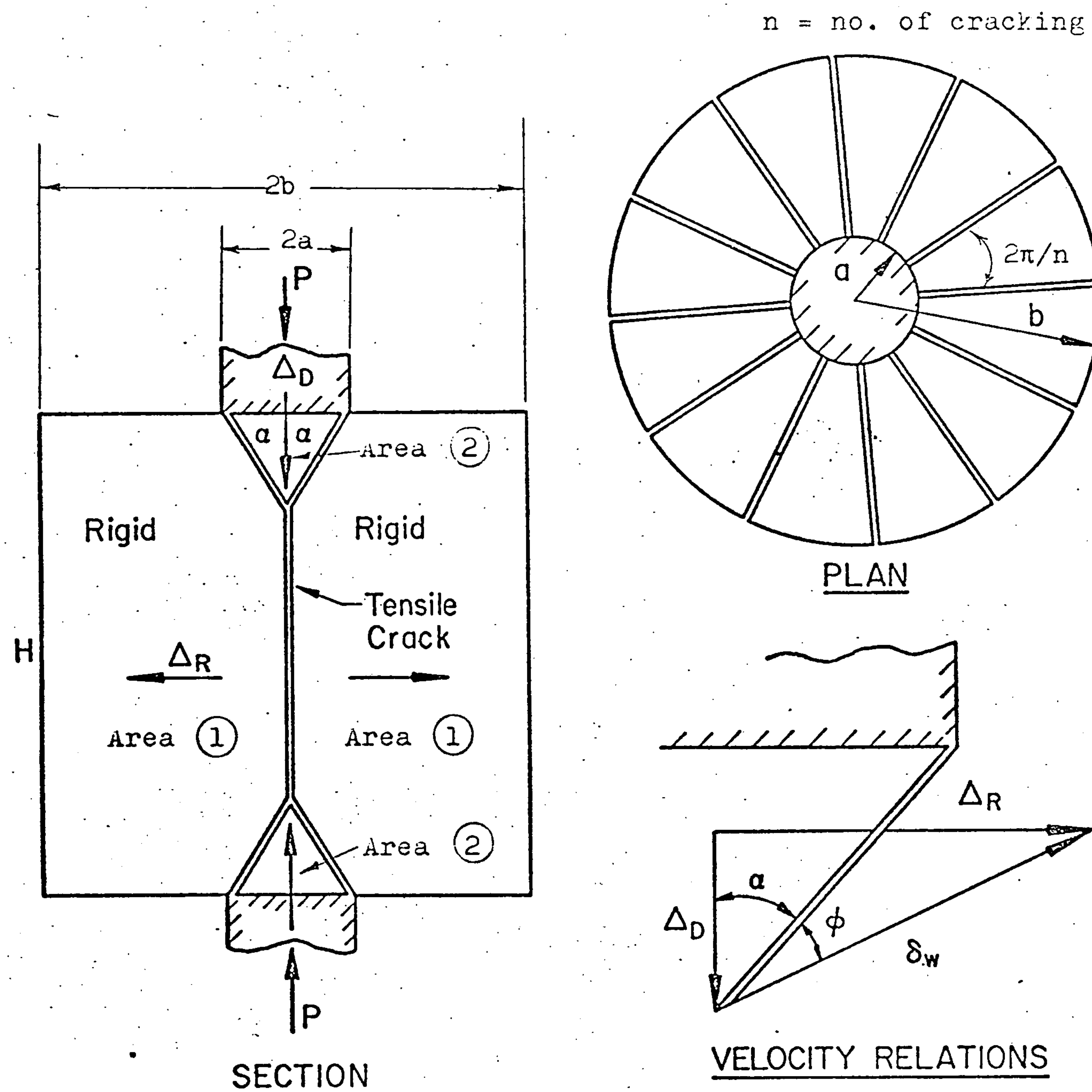

Fig. 4 Failure Mechanism of a Double Punch Test

Appendix A

Figure 4 shows diagrammatically an ideal failure mechanism for a double punch test on a cylinder specimen. It consists of many simple tension cracks along the radial direction and two cone-shape rupture surfaces directly beneath the punches. The cone-shapes move toward each other as a rigid body and displace the surrounding material horizontally sideways. The relative velocity vector δ_w at each point along the cone surface is inclined at an angle ϕ to the surface. The compatible velocity relation is also shown in Fig. 4.

From Limit Theorem:

The internal energy dissipation

= (Discontinuity surface) (Tensile stress)

(Horizontal component of velocity)

From Fig. 4:

The total area of specimen = 2bH

Area 1 = 2bH - 2 (1/2) (2a) (a cot α)

Area 2 (cone surface)

$$= 2\ (\pi a^2/\sin\alpha)$$

The internal energy dissipation in area 1 equals:

$$n\ (2bH - 2a^2 \cot\alpha)\ (\sigma_t)\ (\Delta_R\ 2\pi/n) \qquad (1)$$

The internal energy dissipation in area 2 equals:

$$(2\pi a^2/\sin\alpha)\ [q_u\ (1-\sin\emptyset)/2]^*\ (\delta_w) \qquad (2)$$

*see Ref. 4

The total internal energy dissipation equals Eq. 1 plus Eq. 2 yield:

$$(2bH - 2a^2 \cot \alpha) (\sigma_t) (\Delta_R \ 2\pi) + \pi a^2/\sin \alpha \ q_u \ (1-\sin \emptyset) \ \delta_w \tag{3}$$

The work of external loads

$$= \text{(Load) (Vertical component of velocity)}$$

$$= (2P) \ (\Delta_D)$$

$$= 2P \ \delta_w \cos \ (\alpha + \emptyset) \tag{4}$$

Equating the external rate of work (Eq. 4) to the total rate of internal dissipation (Eq. 3) yields the value of the upper bound on the applied load P,

$$\frac{P}{\pi a^2} = \frac{1 - \sin \phi}{\sin \alpha \cos \ (\alpha + \phi)} \frac{q_u}{2} + \tan \ (\alpha + \phi) \ (\frac{bH}{a^2} - \cot \alpha) \ \sigma_t \tag{5}$$

in which α is the as yet unknown angle of the cone, a is the radius of the punch and b and H are the specimen dimensions (Fig. 4).

The upper bound has a minimum value when α satisfies the condition $\partial P^u/\partial \alpha = 0$, which is

$$\cot \alpha = \tan \phi + \sec \phi \ \{1 + \frac{\frac{bH}{a^2} \cos \phi}{\frac{q_u}{\sigma_t}[\frac{1 - \sin \phi}{2}] - \sin \phi}\}^{1/2} \tag{6}$$

valid for

$$\alpha \geq \tan^{-1} (\frac{2a}{H})$$

and Eq. 2 can be reduced to

$$\frac{P}{\pi a^2} = \sigma_t \; [\frac{bH}{a^2} \tan \; (2\alpha + \phi) \; -1] \tag{7}$$

For soil, the typical values are: $q_u = 10 \; \sigma_t$ and $\phi = 20°$, and assuming 2a = 1 in., 2b = 4 inches and H = 4.6 inches, the upper bound has a minimum value at the point where $\alpha = 14.2°$, and Eq. 7 gives

$$P \leq P^u = \pi \; (1.12 \; bH - a^2) \; \sigma_t \tag{8}$$

It is found that the value of the coefficient 1.12 which appeared in Eq. 8 is not too sensitive to the internal friction angle ϕ. For example, ϕ varies from 0° to 30° and the value of the coefficient varies from 0.84 to 1.32, respectively. The average value of the coefficient is 1.08.

As concluded in Reference 4, the upper bound solution so obtained is in face close to the correct values. It seems, therefore, reasonable to take Eq. 9

$$\sigma_t = \frac{P}{\pi \; (1.0 \; bH - a^2)} \tag{9}$$

as a working formula for computing the tensile strength in a double punch test for all soil.

For other material, such as concrete, rock and stabilized materials, the typical values are: $q_u = 10\sigma_t$, and $\phi = 30°$ and assuming 2a = 1.5 in., 2b = 6 in. and H = 8 in., the upper bound has a minimum value at the point $\alpha = 10°$ and Eq. 7 gives:

$$P \leq P^u = \pi\ (1.19\ bH - a^2)\ \sigma_t \tag{10}$$

It is found that the value of the coefficient 1.19 appearing in Eq. 10 is not too sensitive to the dimensions used in a double punch test.

For Example: (Using 6 inch diameter specimen)

Ht. of Specimen, H	Punch Size, 2a	Coefficient
4.0"	1.0"	1.20
8.0"	1.0"	0.97
6 "	1.5"	1.32
10 "	1.5"	1.11

As concluded in Ref. 4, the upper bound solution so obtained is close to the correct value. It seems, therefore, reasonable to take Eq. 11.

$$\sigma_t = \frac{P}{\pi\ (1.2\ bH - a^2)} \tag{11}$$

as a working formula for computing the tensile strength in a double punch test.

REFERENCES

1. ASTM, 1970 Annual Book of ASTM Standards, Part 11.

2. Hyland, M. W. and Chen, W. F., Bearing Capacity of Concrete Blocks, ACI, Vol. 67, pp. 228-236, March 1970.

3. Chen, W. F., Double Punch Test for Tensile Strength of Concrete, ACI, 1970, to appear.

4. Chen, W. F. and Drucker, D. C., Bearing Capacity of Concrete Blocks or Rock, Journal of the Engineering Mechanics Division, Proc. ASCE, Vol. 95, No. EM4, pp. 955-978, August 1969.