Today decides tomorrow!!!

Shear Strength of Tire Derived Aggregate (TDA)

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Background Information

- At the end of 2005, the U.S. generated approximately 300 million scrap tires
- Historically, these scrap tires took up space in landfills or provided breeding grounds for mosquitoes and rodents when stockpiled or illegally dumped
- Fortunately, markets now exist for 82% of these scrap tires-up from about 17% in 1990
- These markets-both recycling and beneficial use-continue to grow
- The remaining scrap tires, however, are still stockpiled or landfilled

Background Information

Waste tires were used as follows:

- 155 million (52%) were used as fuel (TDF)
- 49 million (16%) were recycled or used in civil engineering projects
- 30 million (10%) were converted into ground rubber and recycled into products
- 7.4 million (2.5%) were converted into ground rubber and used in rubber-modified asphalt
- 6.9 million (2.3%) were exported
- 6.1 million (2.0 %) were recycled into cut/stamped/punched products
- 3 million (1%) were used in agricultural and miscellaneous uses

Scrap Tire Markets

- The 3 largest scrap tire markets are:
  - Tire derived fuel
  - Civil engineering applications
  - Ground rubber applications/ rubberized asphalt concrete
- Both recycling and beneficial use of scrap tires has expanded greatly in the last decade through increased emphasis on recycling and beneficial use by state, local and Federal governments, industry, and other associations
- Unfortunately, even with all of the reuse and recycling efforts underway, not all scrap tires are being used beneficially

Civil Engineering Applications

- The civil engineering market encompasses a wide range of uses for scrap tires
- Scrap tire material typically replaces other material currently used in construction such as lightweight fill materials, drainage aggregate, or even soil
- A considerable amount of tire shreds for civil engineering applications come from stockpile abatement projects
- Tires that are reclaimed from stockpiles are usually dirtier than other sources of scrap tires and are typically rough shredded

Tire Derived Aggregate (TDA)

Definition:

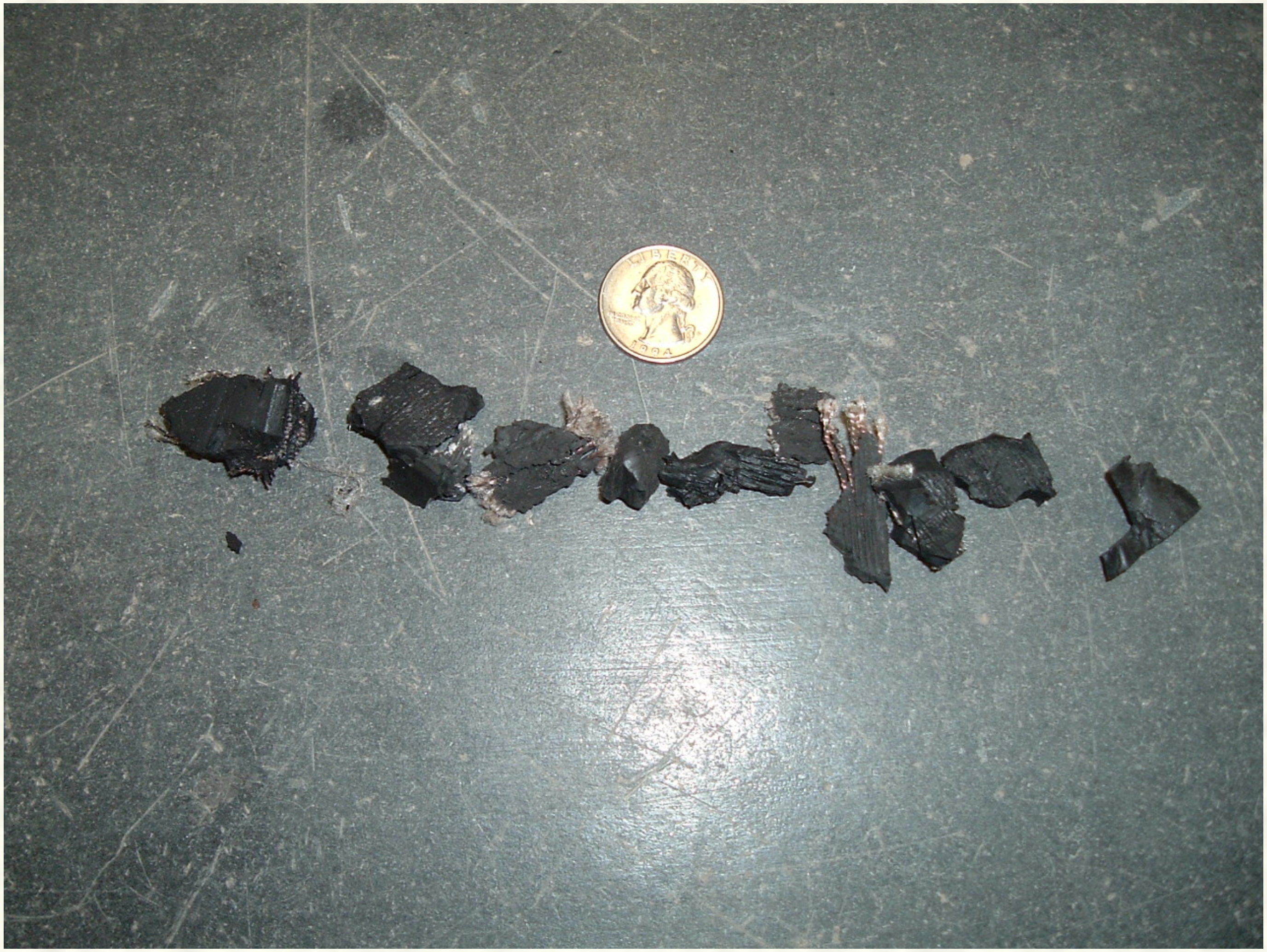
Pieces of processed tires that have a consistent shape and are generally between 25mm (1 in.) and 300mm (12 in.) in size.

Small Shred Size

Large Shred Size

Crumb Rubber Sample

Rubber Buffings



Size Comparison

Civil Engineering Applications

- Subgrade Fill and Embankments
- Backfill for Retaining Walls and Bridge Abutments
- Subgrade Insulation for Roads
- Lateral Edge Drains
- Vibration Damping Layer Beneath Rail Lines
- Landfill Applications
- Septic System Drain Fields

Subgrade Fill and Embankments

- Tire shreds can be used to construct embankments on weak, compressible foundation soils
- Tire shreds are viable in this application due to their light weight
- Using tire shreds as a lightweight fill material may be significantly cheaper than alternatives
- Subgrade fill and embankment applications include: protecting roads from erosion, enhancing the stability of steep slopes along highways, and reinforcing shoulder areas

Backfill for Walls and Bridge Abutments

- The light weight of the tire shreds reduces horizontal pressures and allows for construction of thinner, less expensive walls
- Tire shreds can also reduce problems with water and frost build up behind walls because tire shreds are free draining and provide good thermal insulation

Engineering Properties of TDA (After Humphrey, 2003)

1. Gradation
2. Specific Gravity and Absorption capacity
3. Compressibility
4. Resilient Modulus
5. Time Dependent Settlement of TDA Fills
6. Lateral Earth Pressure
7. Shear Strength
8. Hydraulic Conductivity (Permeability)
9. Thermal Conductivity

Mechanics of Materials Background

- Continuum Mechanics
  - Uniform distribution of matter
  - No voids
  - Cohesive (all portions are connected together, and have no breaks, cracks, or separations)
- Crumb Rubber and TDA
  - Discrete Material
  - Contains air voids
  - Possesses cohesion
  - Similar Properties to sands and gravels

Continuum Mechanics

- Deformable bodies develop both normal (tension and compression) and shear stresses when acted on by applied loads
- Brittle materials fail in tension perpendicular to the maximum tensile stress
- Ductile materials fail in shear parallel to the maximum shear stress
- Poisson's ratio relates the transverse contraction to the longitudinal elongation (or vice versa) $0.25 < \mu < 0.34$ for most CE materials

CRUMB RUBBER STRENGTH

- Crumb Rubber can support compression but not tension stresses and typically fails in shear

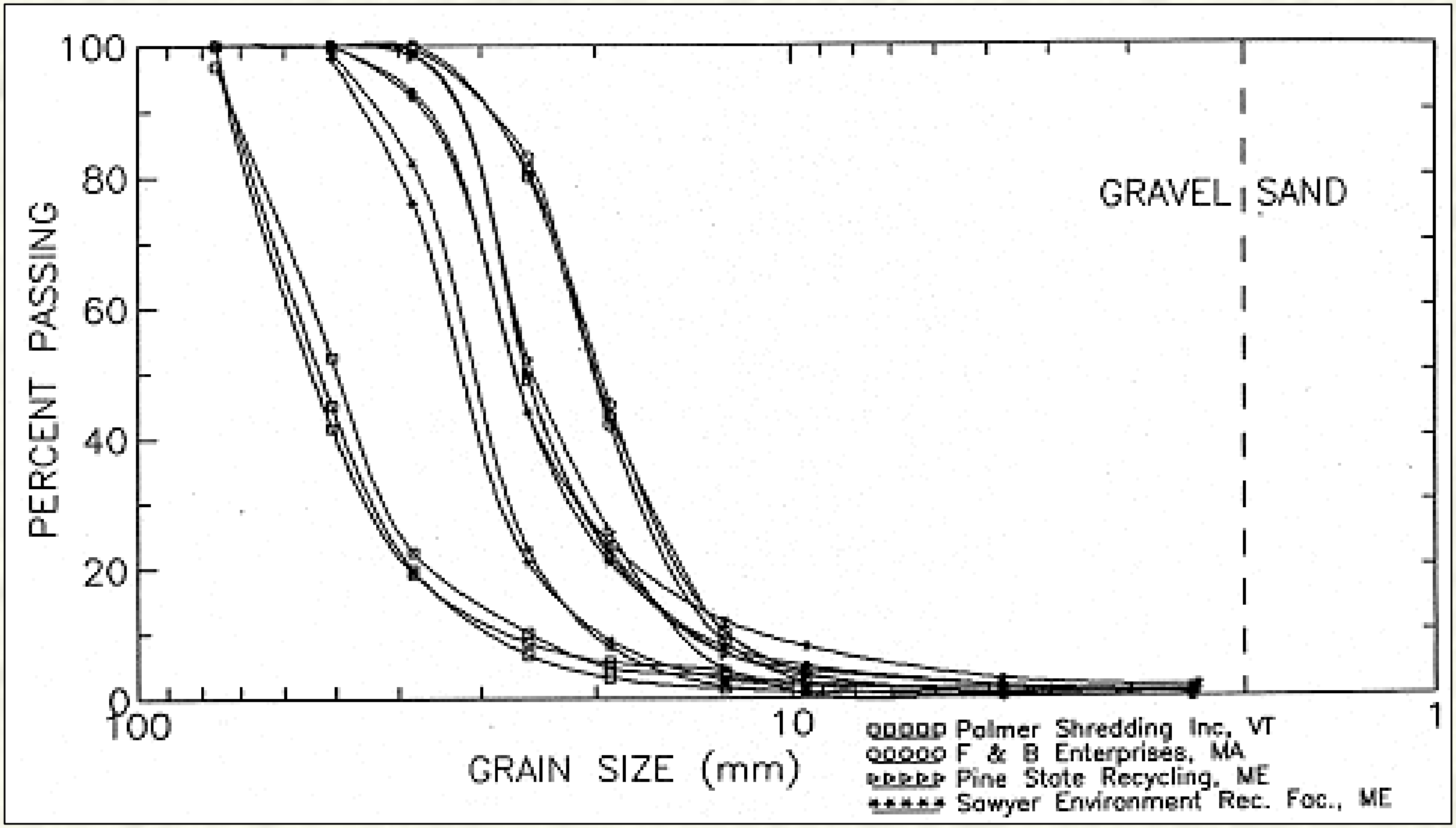
- We will consider three factors affecting the Shear Strength of Crumb Rubber:
  1. Size and shape of the rubber pieces
  2. The density (packing) of the sample at the beginning of the test
  3. Magnitude of the compressive normal loading

1. Size and Shape of the Particles

- Our crumb rubber sample is “uniformly graded” i.e. all the particles are nearly the same size and are approximately cubical in shape
- TDA (Tire shreds) are also fairly uniformly graded but are irregularly shaped
- The following plots show typical gradation curves for TDA, crumb rubber, and rubber buffings

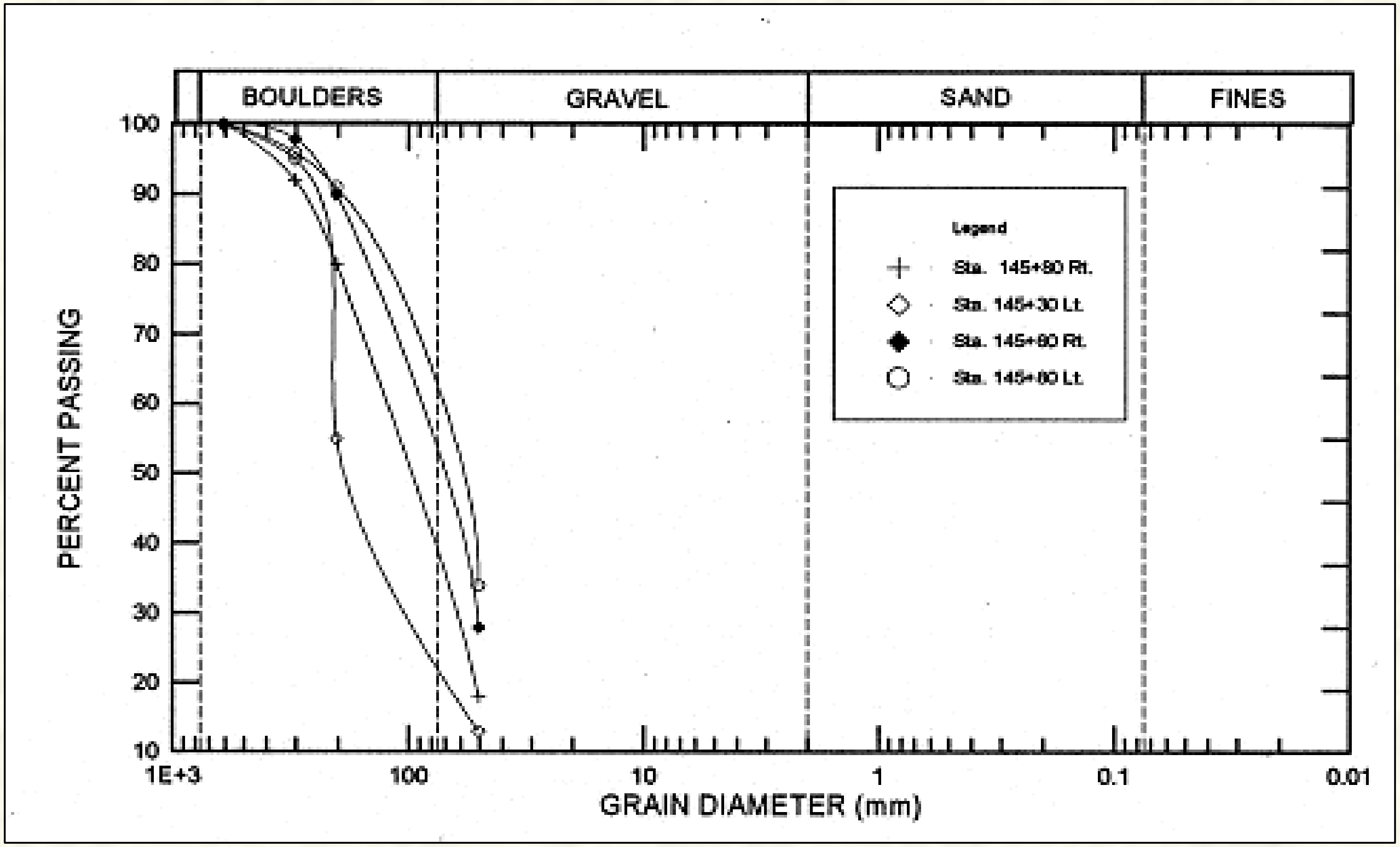
TDA Gradation

3” Maximum Size:

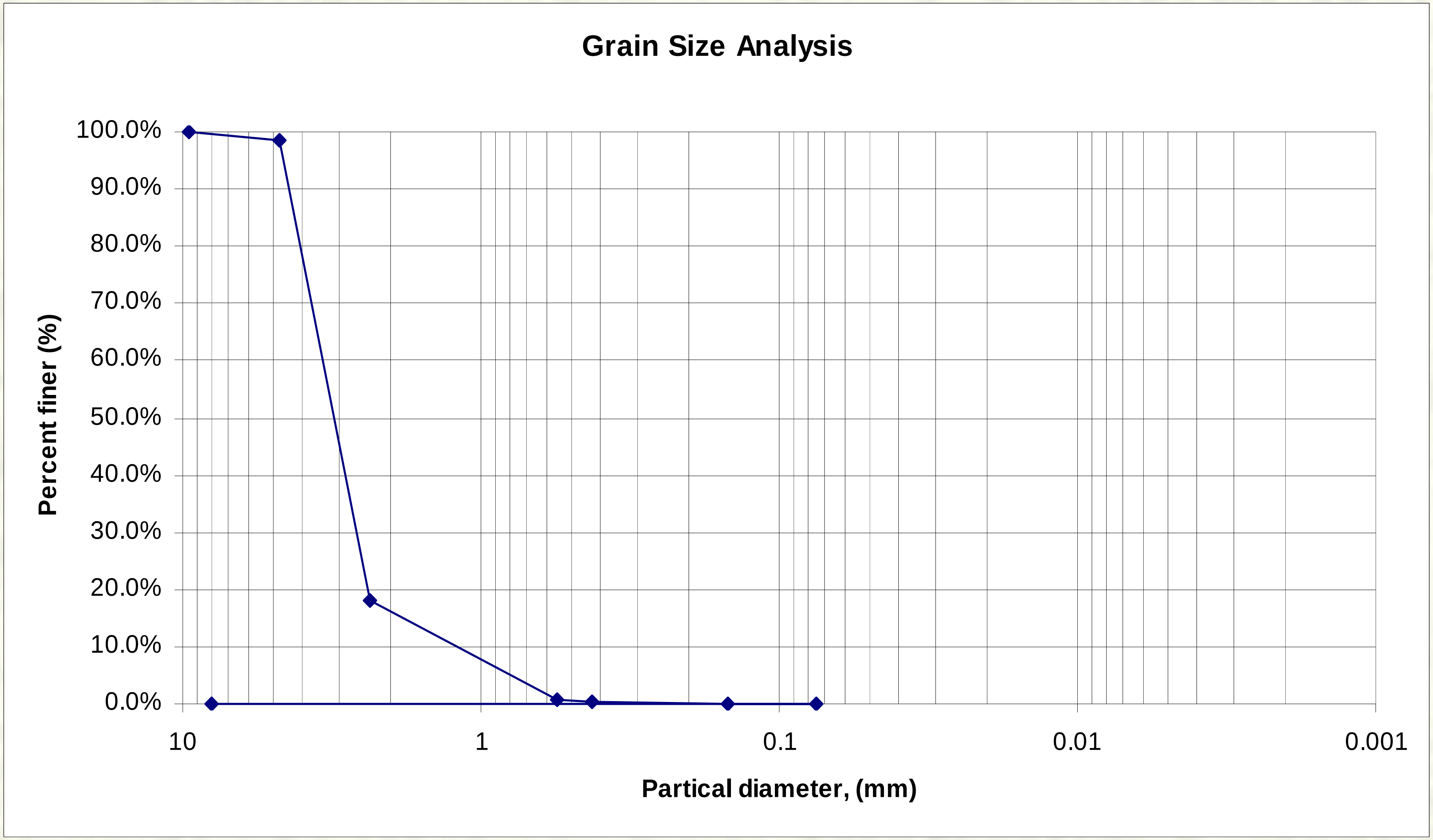


TDA Gradation

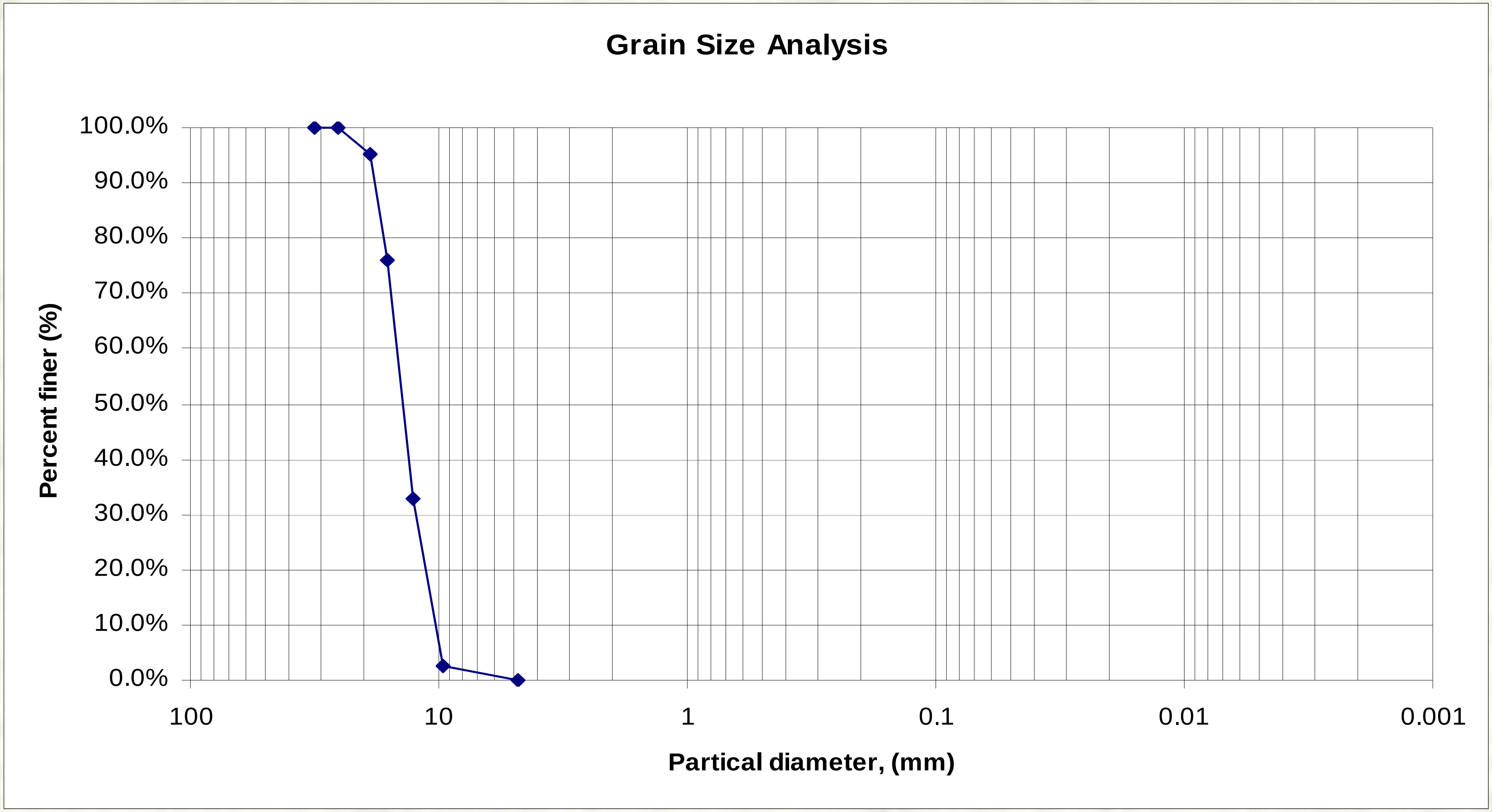
12” Maximum Size:



Crumb Rubber Gradation



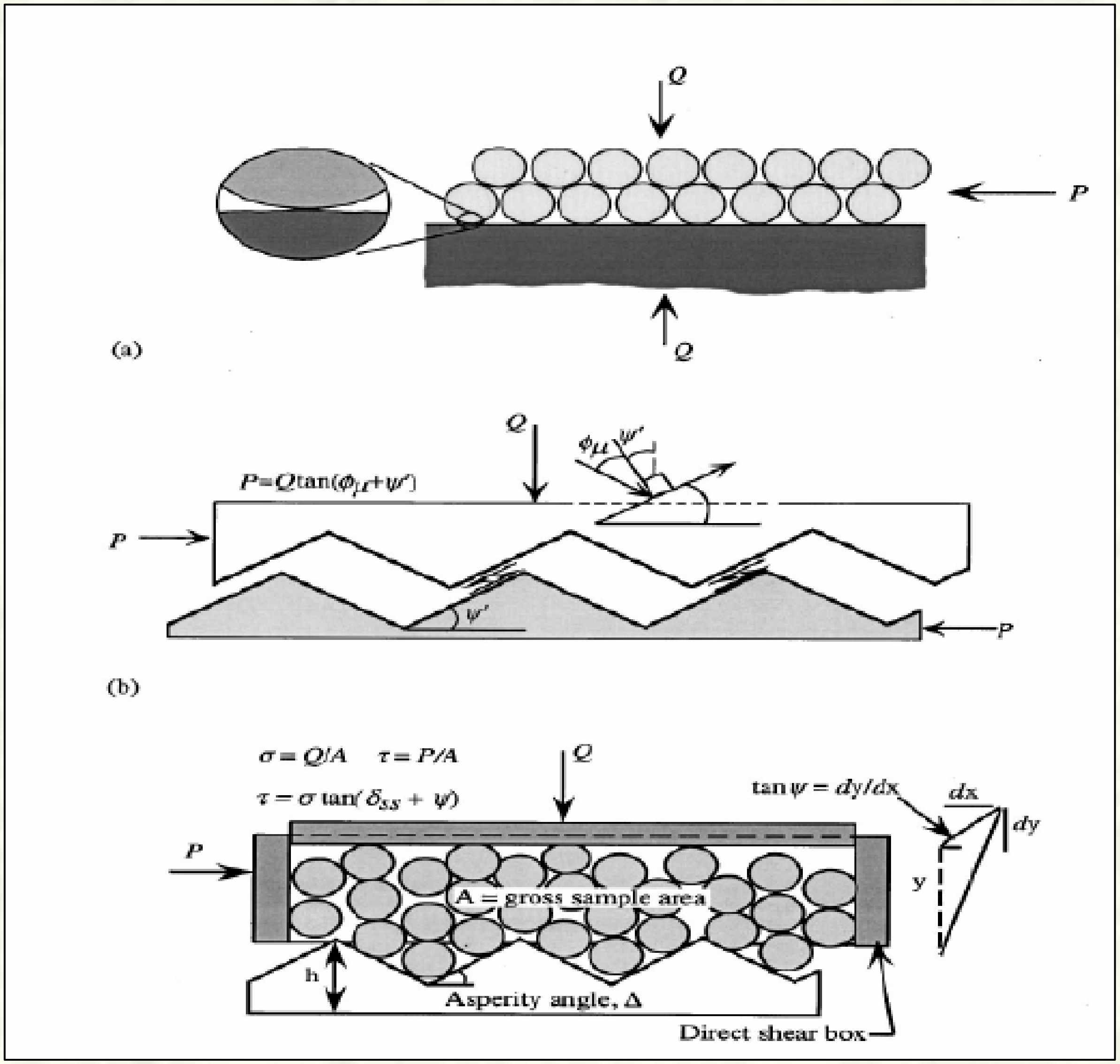
Rubber Buffing Gradation



2. Effects of Density or Packing

- The preparation of the sample may influence the shear stress/strain behavior
- Initially loose samples will decrease in volume as the sample is sheared
- Initially densely packed samples will “Dilate” or expand as the sample is sheared
- Need to measure displacement perpendicular to the direction of loading to determine what you have

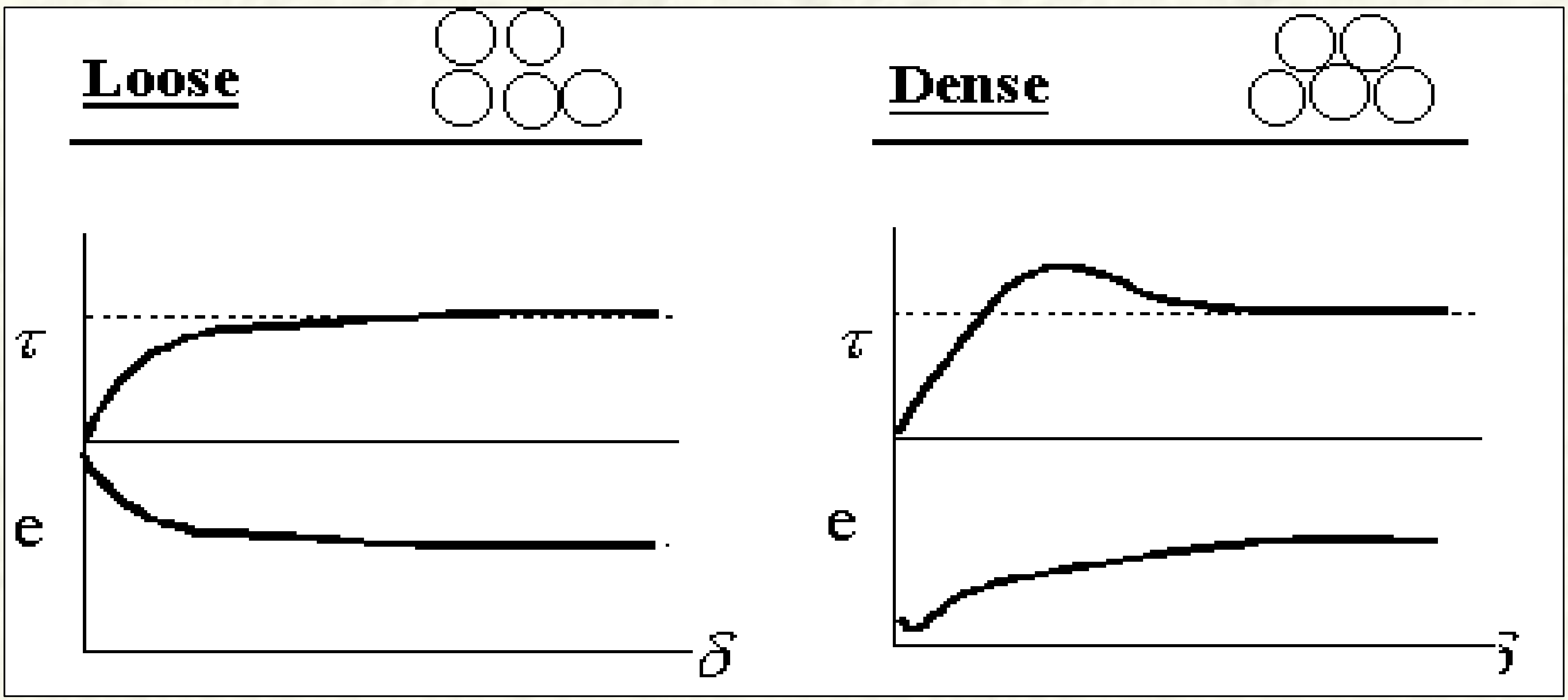
2. Effects of Density or Packing



Effects of Density or Packing

For Uniform Spheres:

(e = void ratio, defined as volume of voids/ volume of solids)



3. Magnitude of the compressive normal loading

- **As the normal force is increased on the sample, the shear stress of the sample increases**
- **The relationship between the normal stress and the shear stress for a granular material like crumb rubber and TDA is given by Mohr-Coulomb failure criteria:**

$$\tau = c + \sigma * \tan\phi$$

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- τ = shear stress on the failure plane
- σ = normal stress on the failure plane
- C = the cohesion intercept (=0 for most granular materials)
- ϕ = angle of internal friction (slope of the line relating shear strees to normal stress

We are interested in Shear Strength

Can be determined in the Lab using one of two common tests:

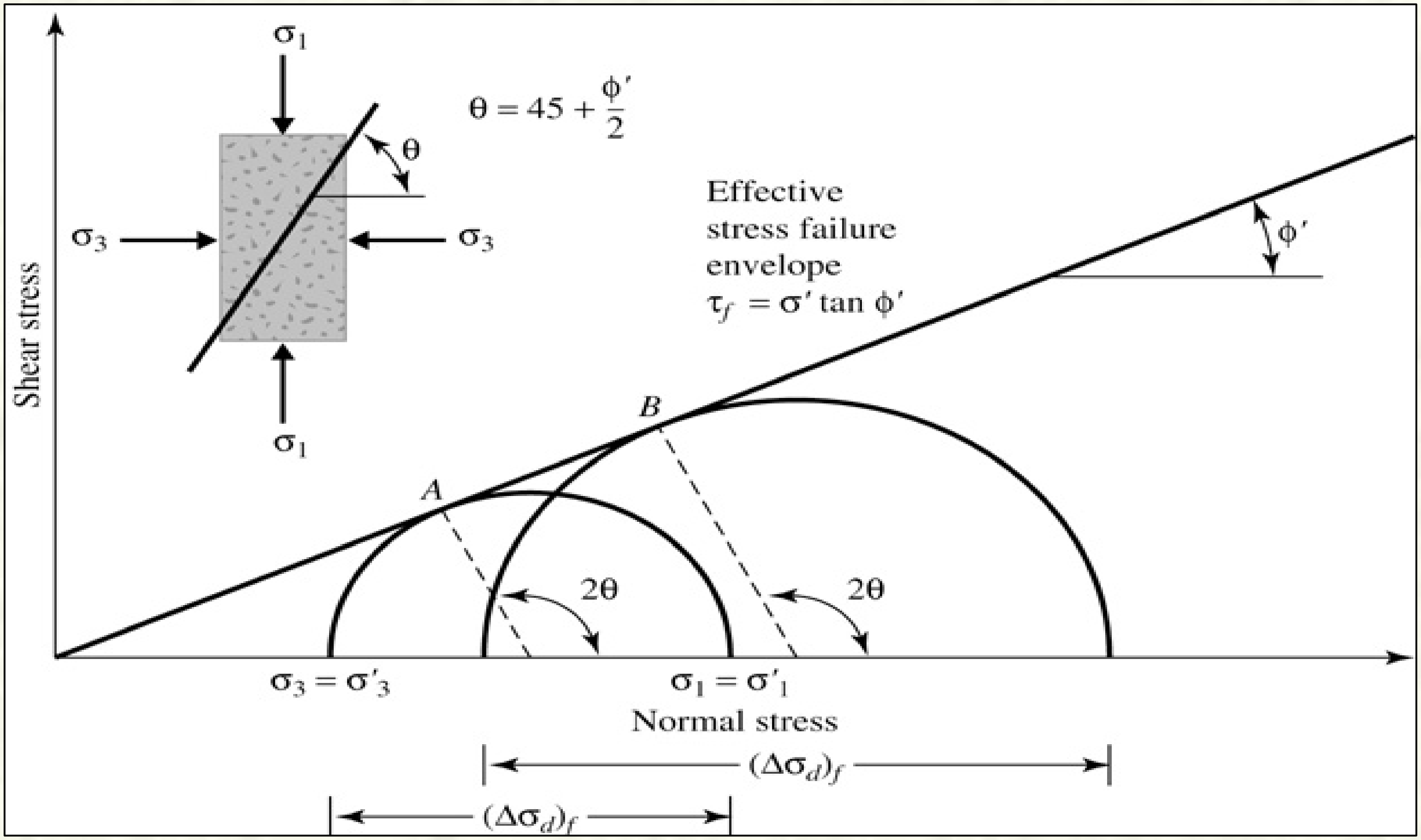
- **Triaxial Test**
- **Direct Shear Test**

Triaxial Test Machine

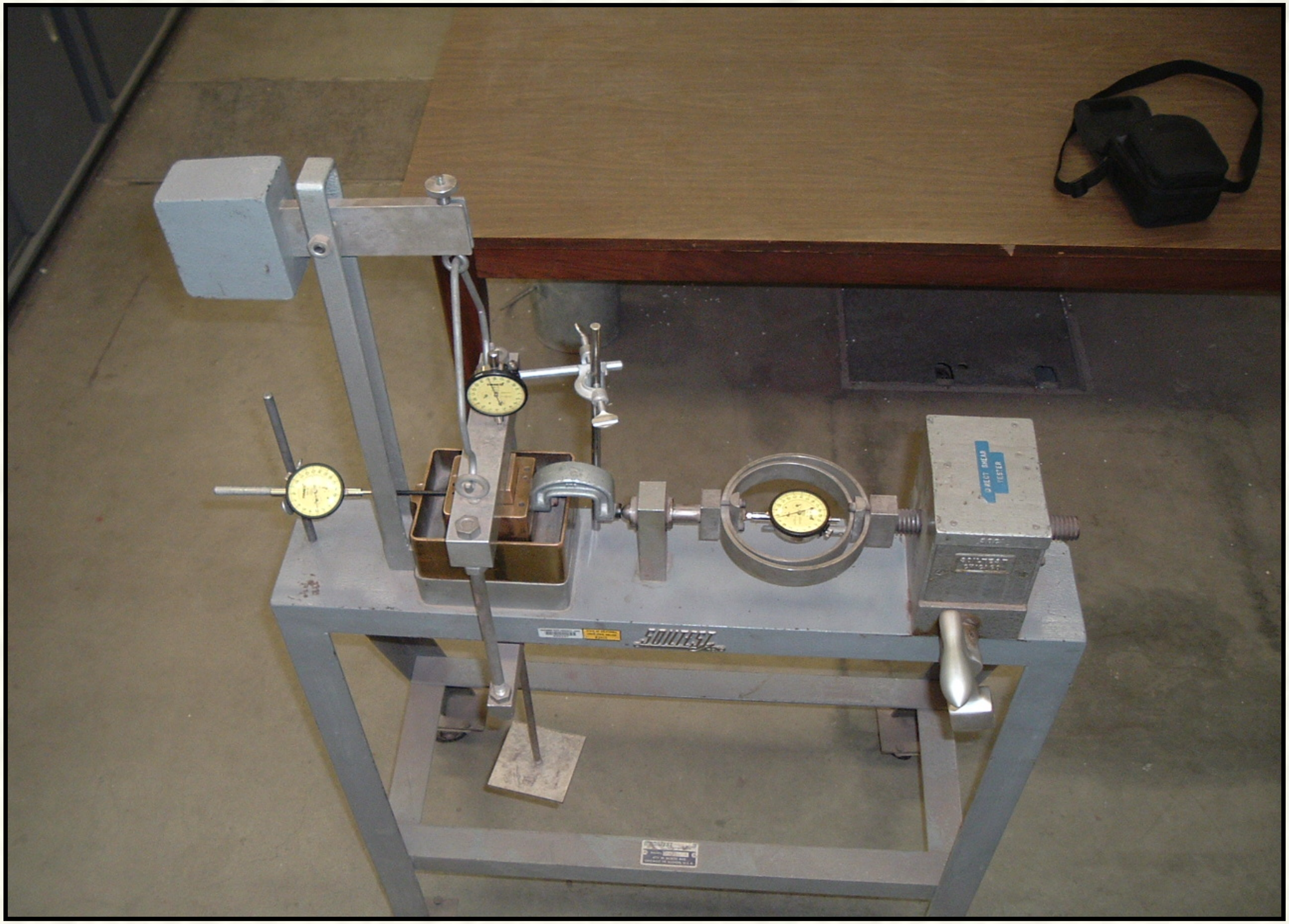
Example Failure Envelope from Triaxial Test

Principal stresses at failure for drained test:

σ_3 = confining pressure $\quad \sigma_1 = \sigma_3 + (\Delta\sigma_d)_f$

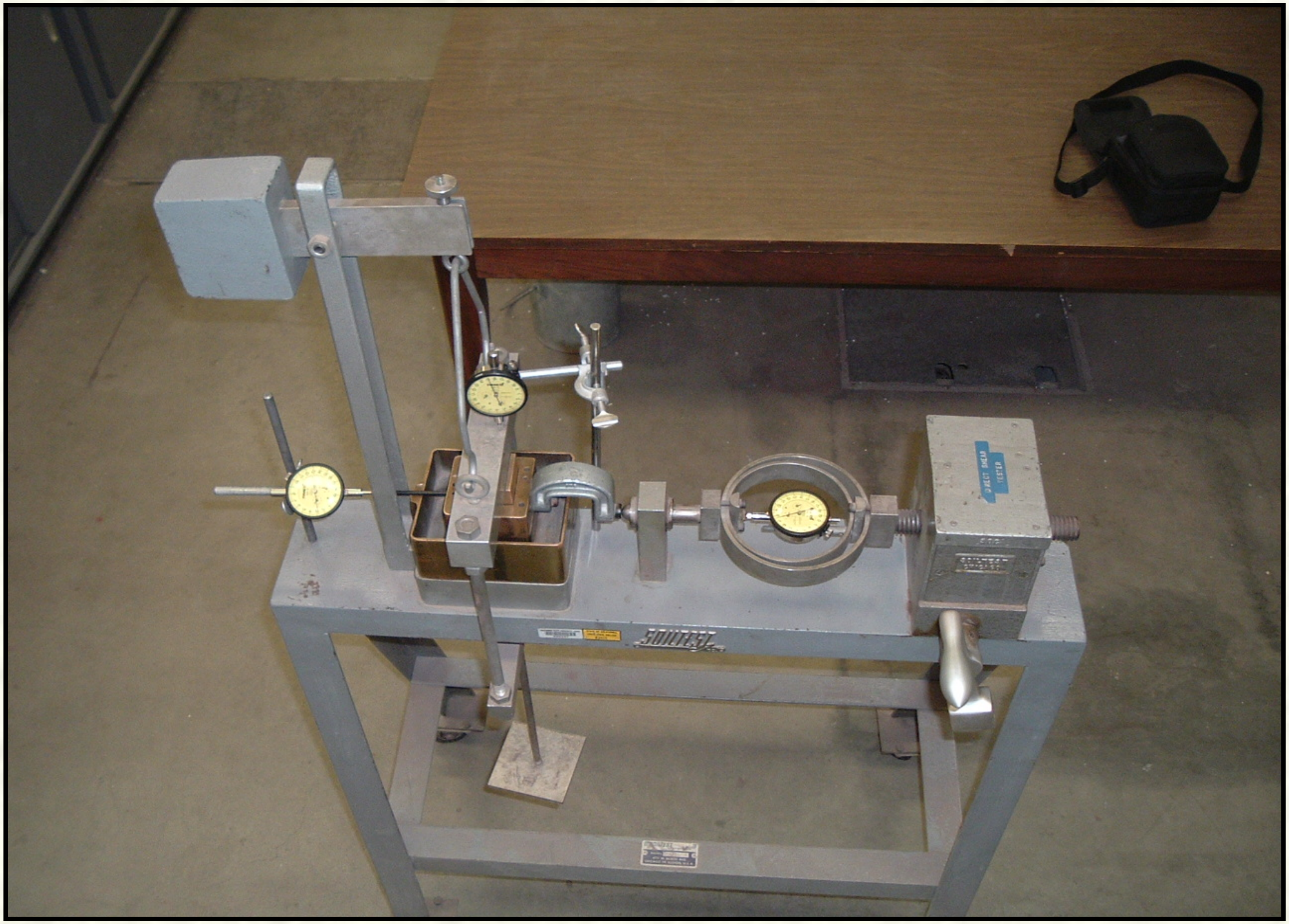


Direct Shear Test Machine

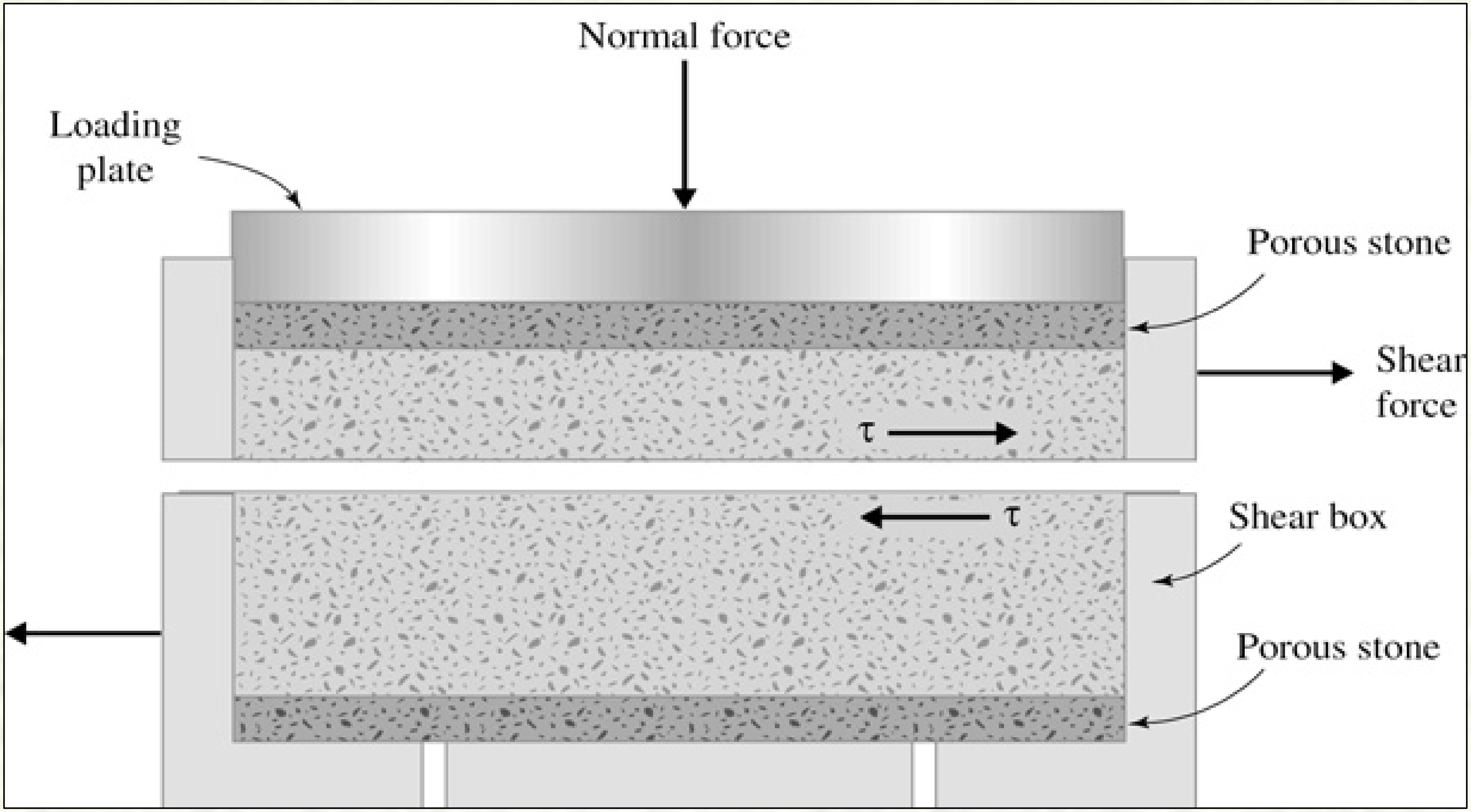


Shear Box

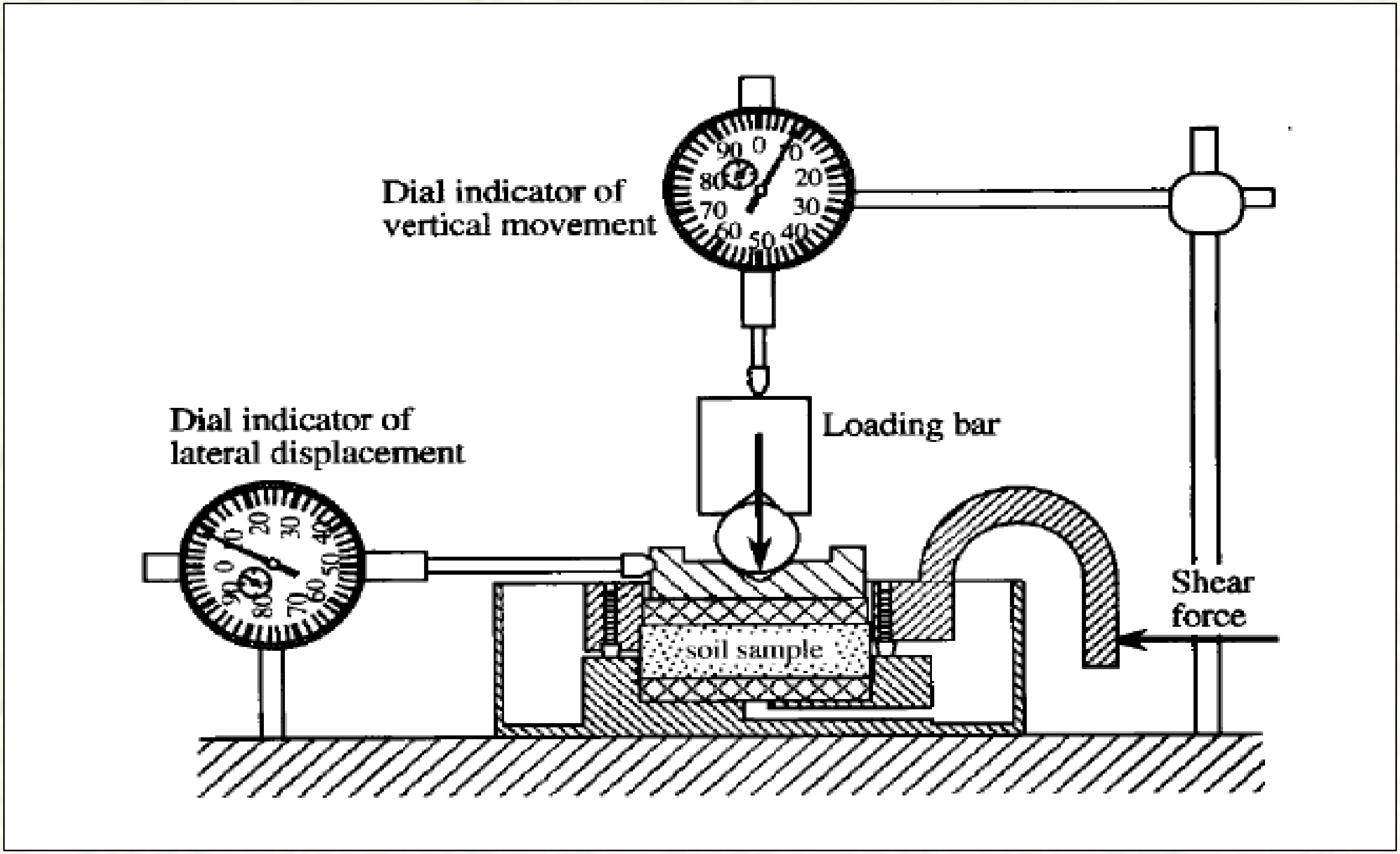
Direct Shear Test Machine



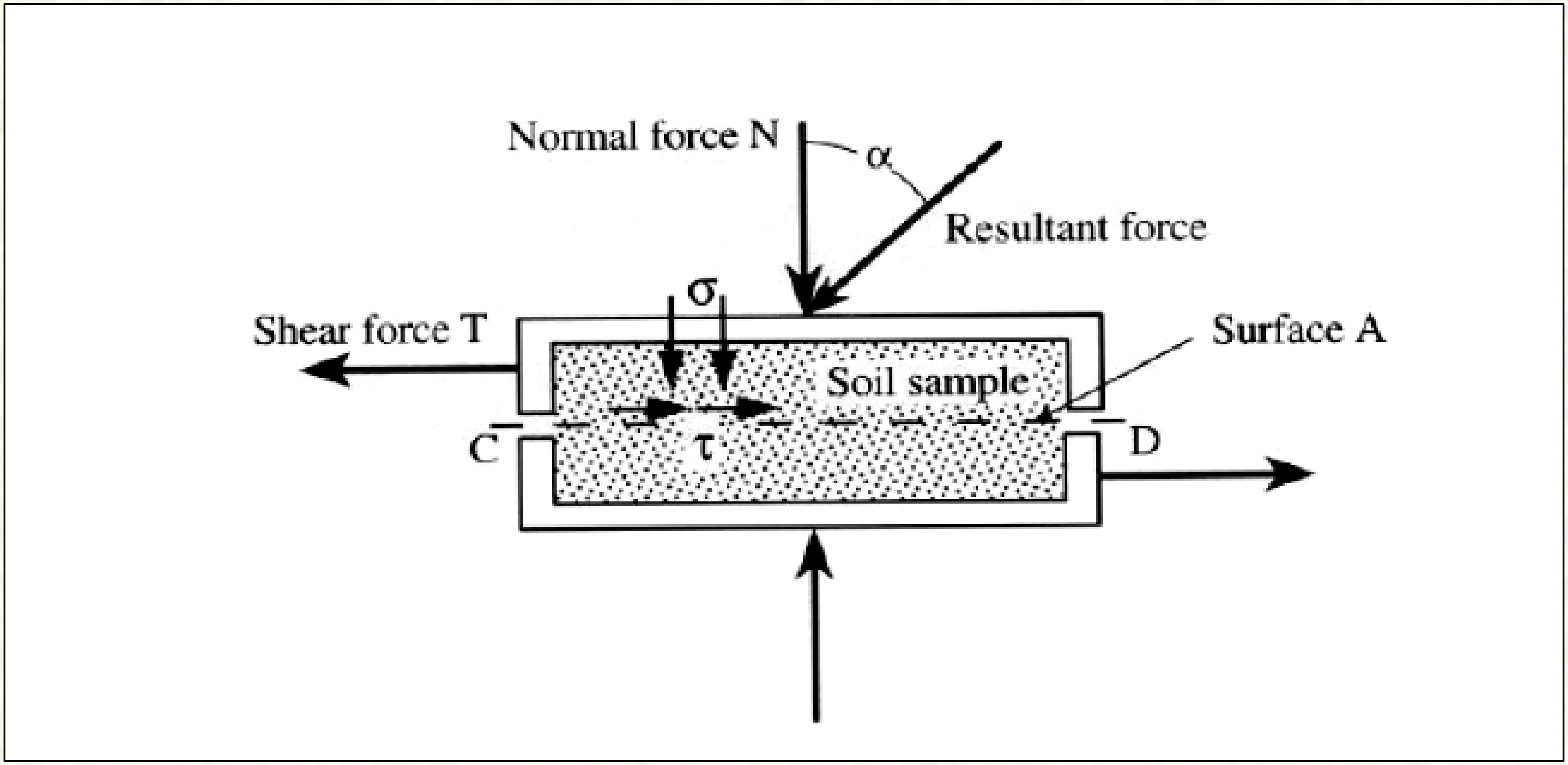
Direct Shear Test



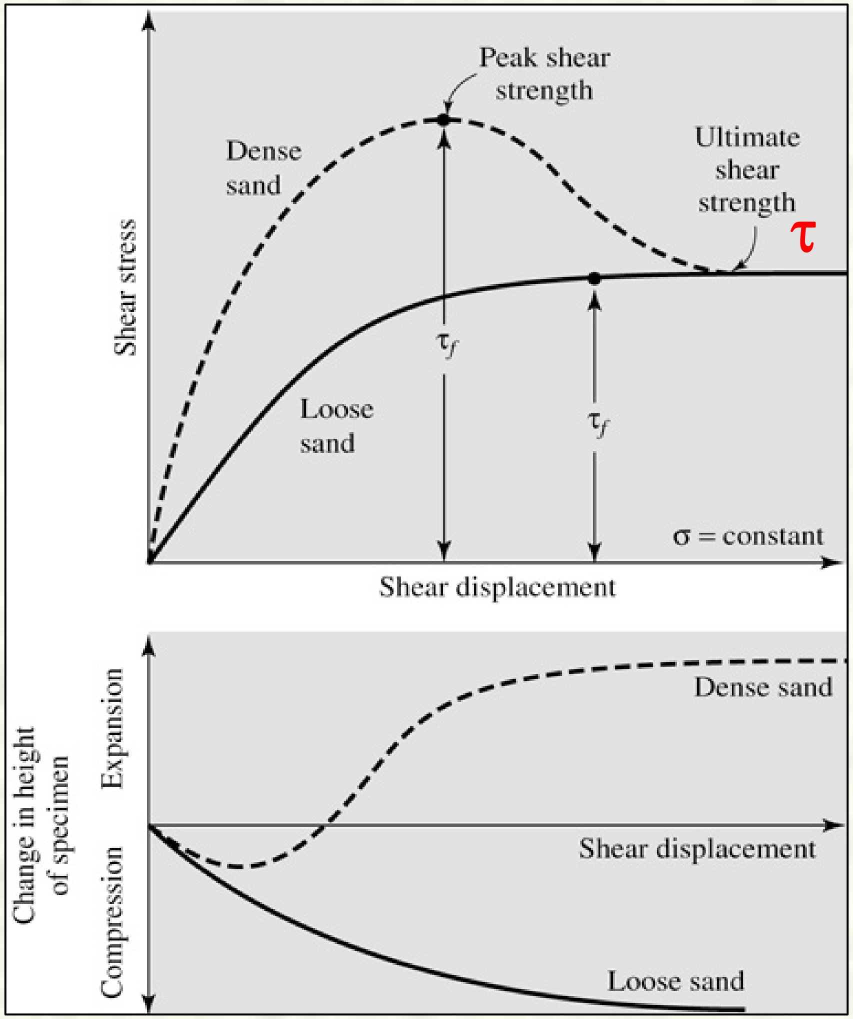
Schematic Showing Direct Shear Equipment



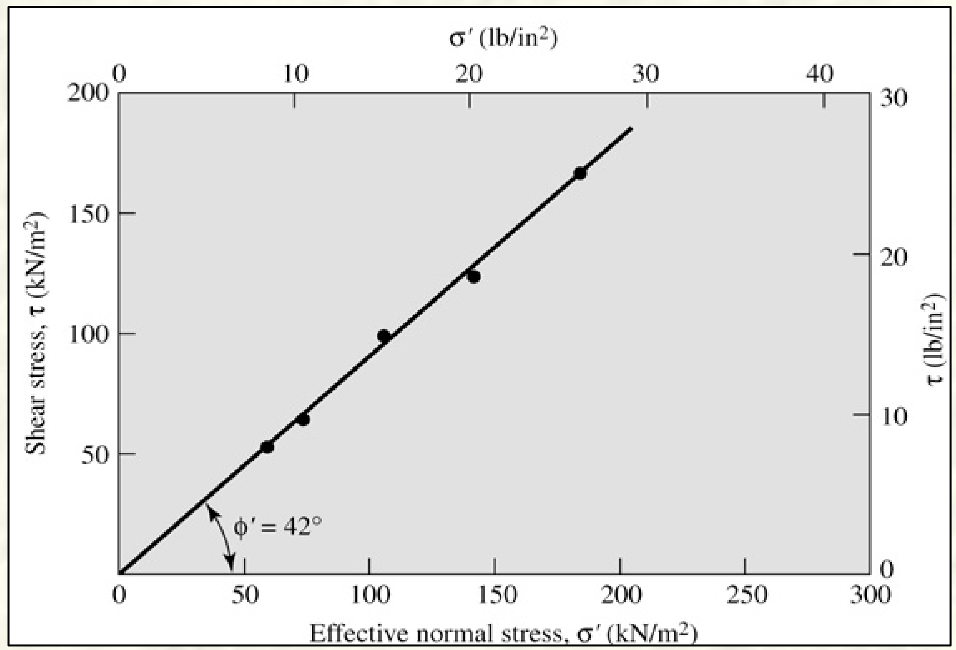
Crumb Rubber Sample in the Direct Shear Box



Example direct shear test curves



Example failure envelope (dry sand, note *c* is zero)



Proving Ring Calibration Data

LOAD RING CALIBRATION DATA (from mfgrs. info)
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Ring No.	Load Limit	Location	Load Equation(s) *	DR limit
92	11,000 N	triaxial	Load = 10650 x DR	1.04 mm
167	11,000 N	"	Load = 10680 x DR	1.04 mm
138	4,500 N	"	Load = 4470 x DR	0.99 mm
180	4,500 N	"	Load = 4007 x DR	1.11 mm
1312	27,000 N	-	Load = 41830 x DR	0.638 mm
1482	2,200 N	qu	Load = 570 x DR Load = 1256 x DR - 600	0.874 mm
1551	2,200 N	-	Load = 567 x DR Load = 1254 x DR - 614	0.984 mm
1589	2,200 N	direct shear (Brown)	Load = 558 x DR (L) Load = 1209 x DR - 710 (h)	1.092 mm
12745	2,200 N	triaxial	Load = 526 x DR Load = 1217 x DR - 1028	1.488 mm
13767	2,200 N	direct shear (silver)	Load = 543 x DR (L Load = 1311 x DR - 862 (h)	1.123 mm

* Load is in Newtons
DR is in millimeters

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Advantages and Disadvantages of Direct Shear Test

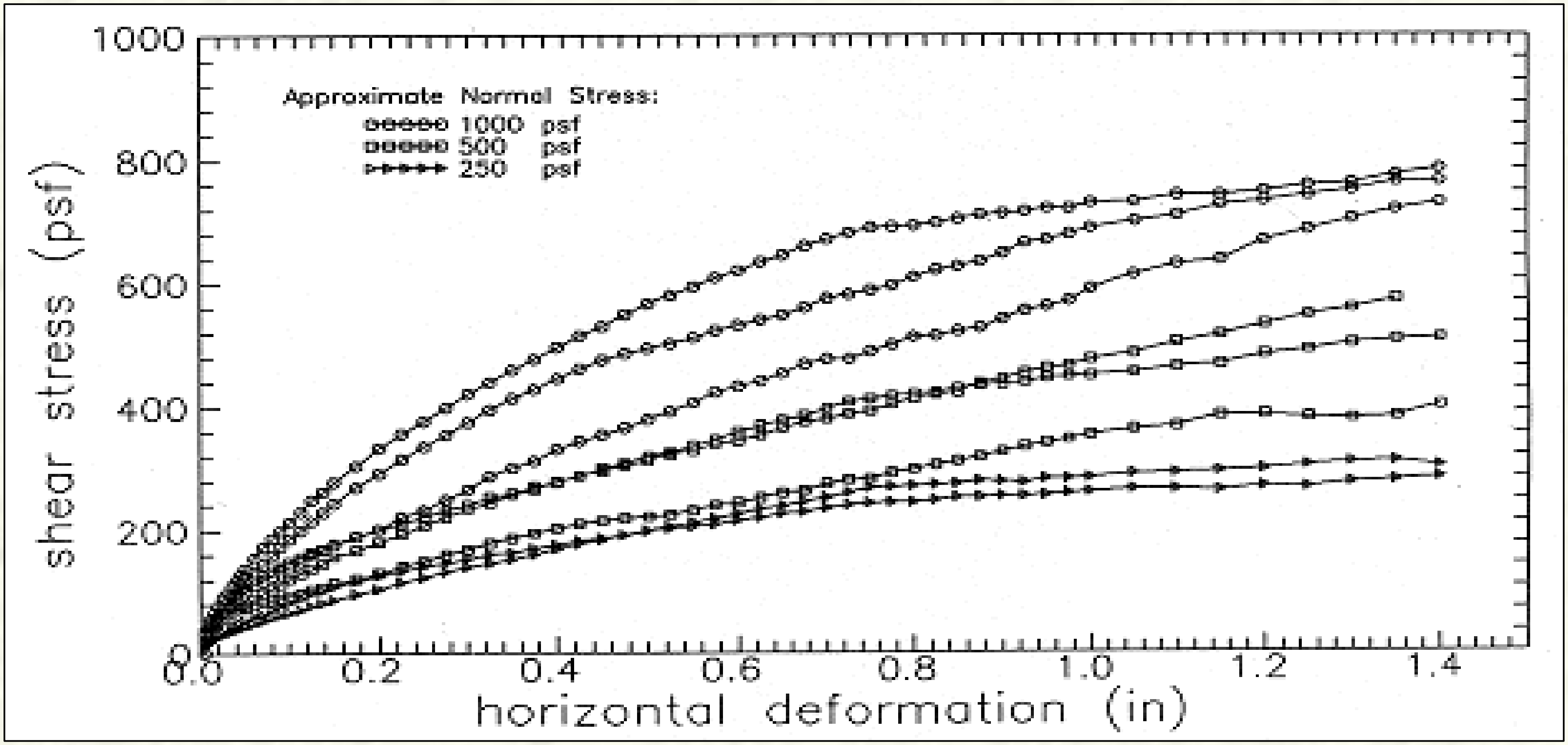
- **Disadvantages:**
  - **Soil is forced to fail along the plane of split of the shear box, instead of along a natural weak plane**
  - **The distribution of shear stress is not uniform, but assumed to be uniform**
- **Advantages:**
  - **Simple to perform**
  - **Good for testing shear strength along contacting surfaces of different materials (e.g., soil and foundation materials)**

Shear Strength

- A direct shear apparatus or a triaxial shear apparatus can be used to measure the shear strength of tire shreds
- However, apparatuses large enough for TDA are rare, so tests are generally completed on 1-in or smaller tire shreds
- The triaxial test shouldn't be used for tire shreds with protruding steel belts

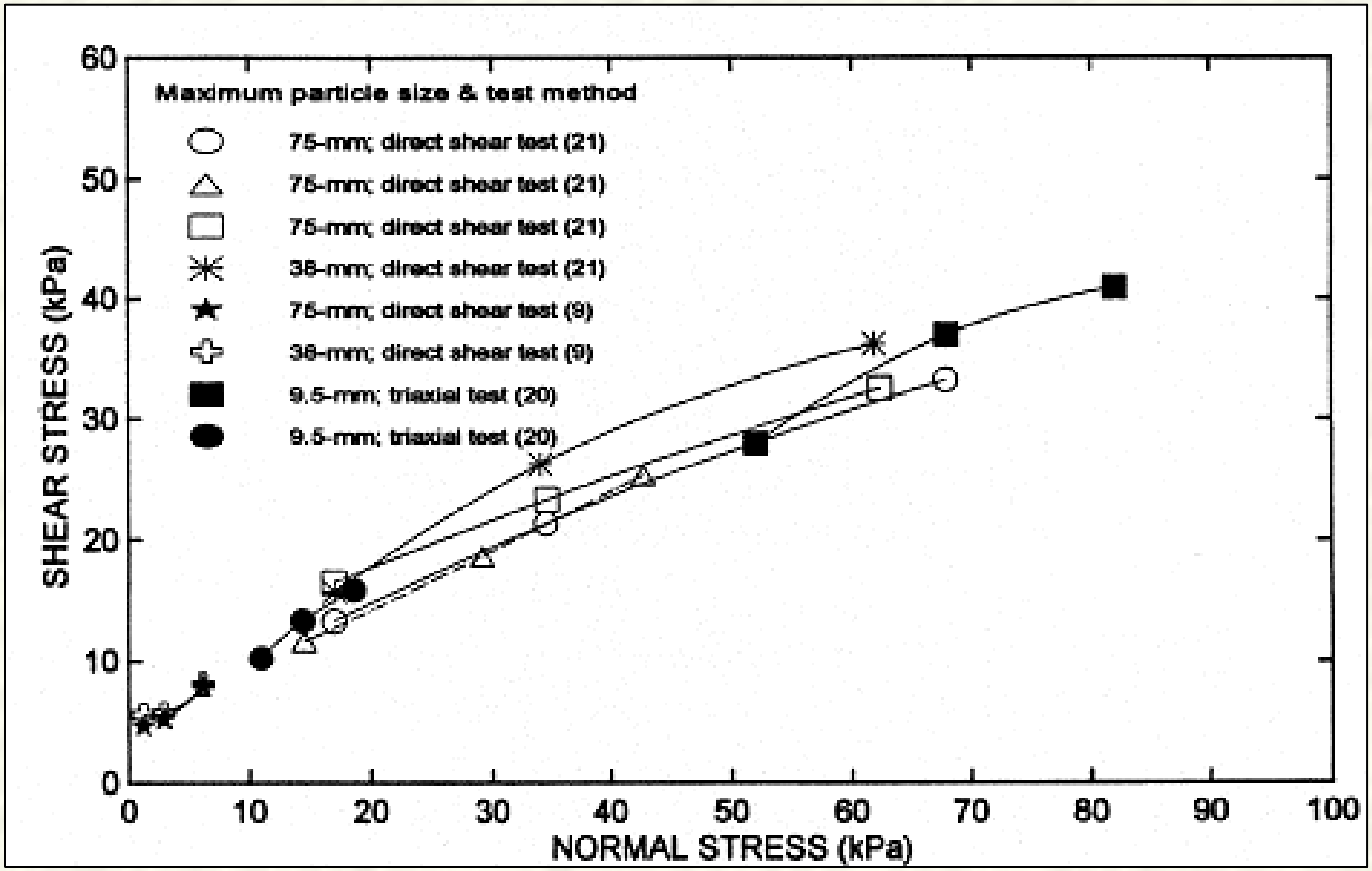
Shear Strength

Shear stress vs. horizontal deformation for Pine State Recycling tire shreds tested in direct shear box (Humphrey, et al., 1992)



Shear Strength

Comparison of failure envelopes of TDA at low normal stress levels **(less than about 2000 psf)**



References:
(21)Humphrey, et al, 1992
(9)Cosgrove, 1995
(20)Benda, 1995

Shear Strength

- These failure envelopes are non-linear and concave down
- Tests on 0.5-in and 1-in tire shreds at higher stress levels produce failure envelopes that are approximately linear
- For high stress tests, using a failure criteria of 15% axial strain, Ahmed (1993) obtained cohesion intercepts from 572 to 689 psf and friction angles from 15.9 to 20.3 degrees

Summary

- In order to determine the strength properties rubber tire particles, lab tests need to be conducted
- The most appropriate method is the direct shear test
- Like soil, the shear strength of rubber particles increases as normal stress increases
- Under normal loading, TDA develops an apparent cohesion

THANK YOU

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