Investigating the Relationship Between the Resilient Modulus and G_{max}

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The Resilient Modulus (M_r)

- A dynamic measure of a material's elastic (Young's) modulus.
  - Relates stress and strain in the material.
  - Commonly measured by taking the slope of an elastic portion of the stress/strain curve
  - Used for many design purposes

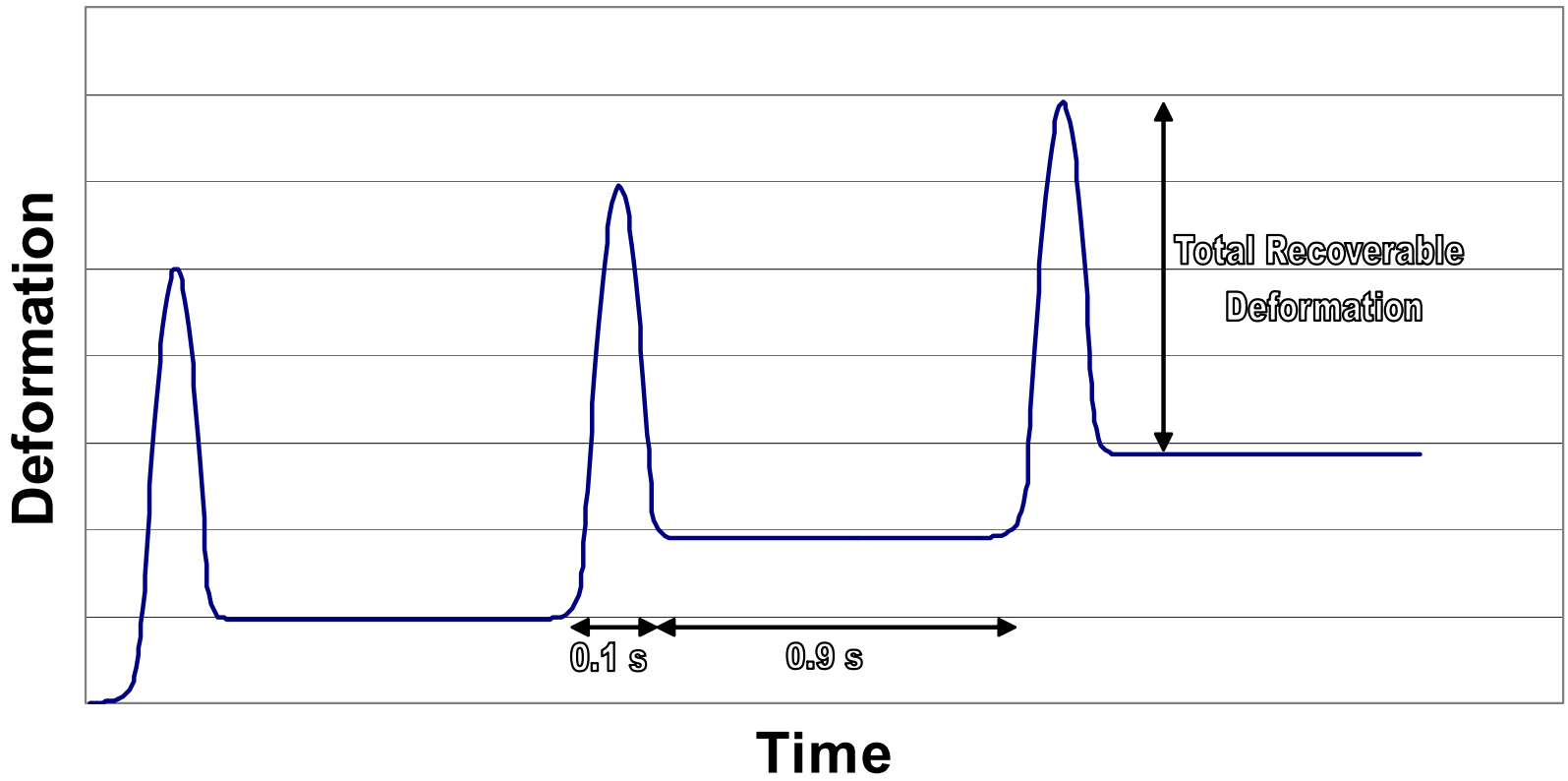
LTPP Protocol 46

- Distributed by the Federal Highway Administration
- Designed to calculate M_r for pavement base and subgrade materials.
- Involves a lengthy triaxial test.

LTPP Protocol 46 Procedure

- Prepare the specimen
- 0.1 second axial haversine load
- 0.9 seconds of material recovery
- Calculate M_r by dividing axial stress by axial strain and repeat

Axial Deformation Versus Time



LTPP Protocol 46 Values

- Seating load
  - 15 psi (103 kPa) confining pressure
  - 15 psi (103 kPa) maximum axial stress
  - 500-1000 load applications
- Actual test
  - 5 confining pressures: 3,5,10,15,20 psi
  - 3 max axial stress values per pressure
  - 100 load applications per stress – only the last 5 are considered in the final calculation

G_{max}

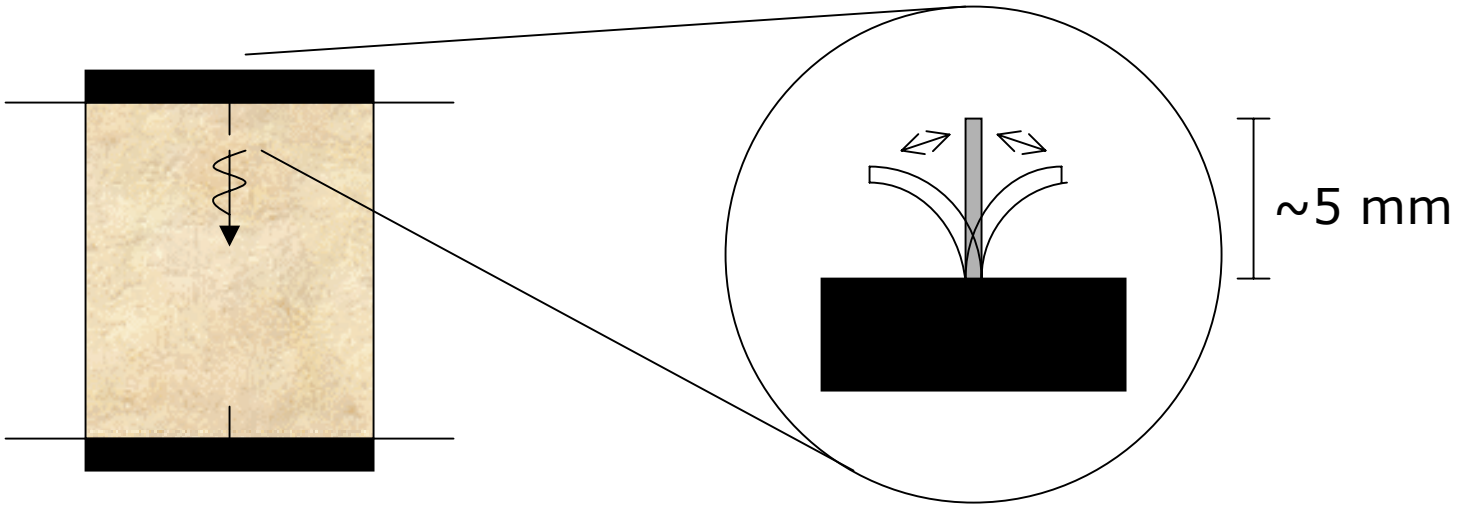
- The apparent value of the elastic shear modulus for very small strains
  - Can be calculated by taking the slope at the end of a very small unloading and reloading curve on the stress/strain diagram
  - Often assumed to be equivalent to M_r
  - Actual relationship not well defined

Bender Elements

- A reliable method for calculating G_{max}

- Relatively simple test
  - Insert piezoelectric strips into the top and bottom of a material specimen
  - Induce the vibration of one strip
  - Record the wavespeed of the resultant shear wave

Bender Elements



- Record C_s, then use this equation:

$$G_{\max} = \rho c_s^2$$

Parametric Study

- Report recently written to see what parameters may impact testing
- Several parameters will have important effects on the results
  - Soil density
  - Moisture content
  - Strain level induced by the elements
  - Other bender element/testing issues

Soil Density (ρ)

- Appears in the G_{MAX} equation:

$$G_{MAX} = \rho c_s^2$$

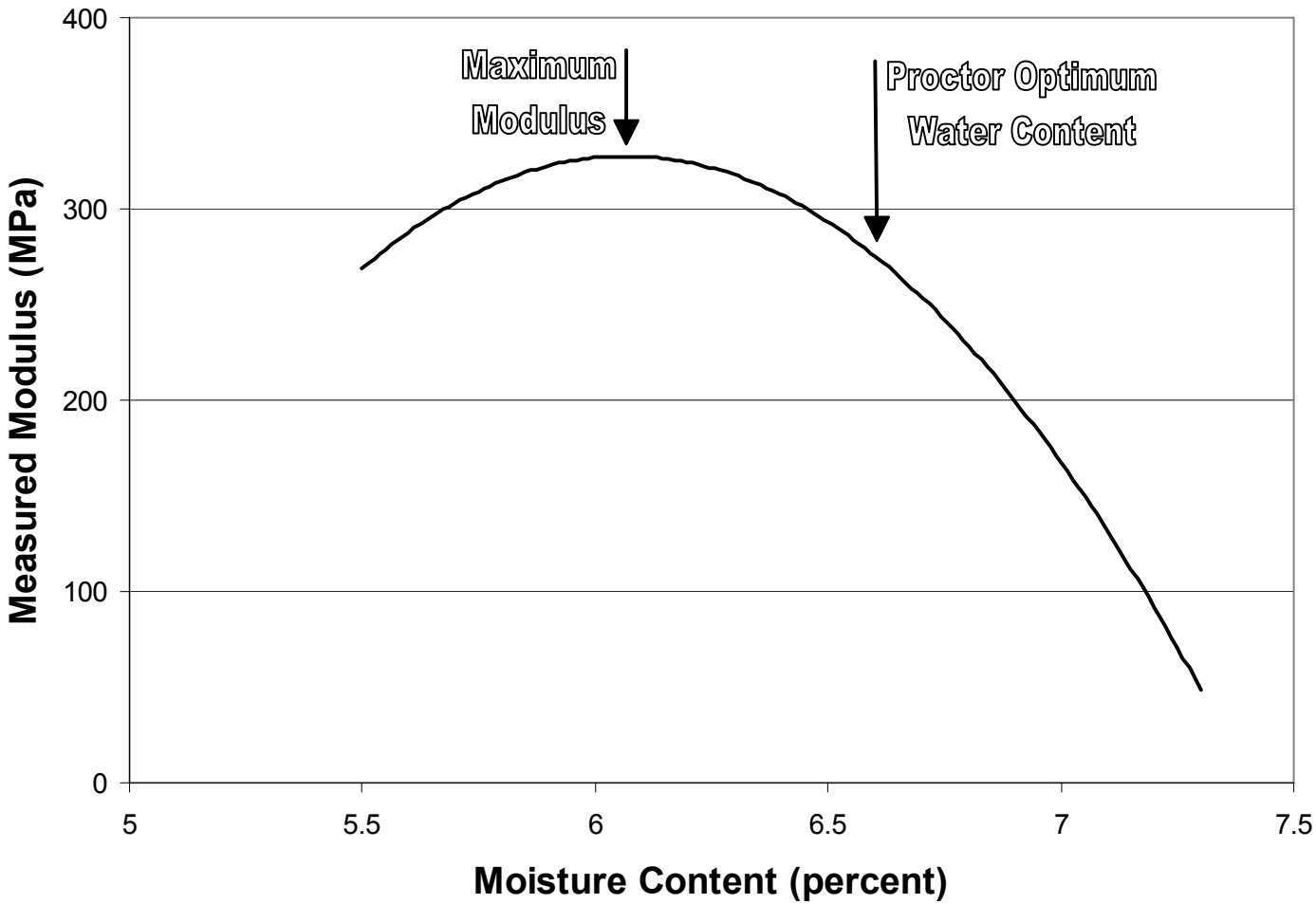
- Should have a known value and be held constant during testing

- Most sands are effectively incompressible within the range being tested (0-20 psi)

Moisture Content

- Used to be difficult to test with bender elements
- Nazarian and Yuan (2001) constructed moisture-modulus curves
- Largest moduli did not occur at Proctor optimum water content: often several percentage points below

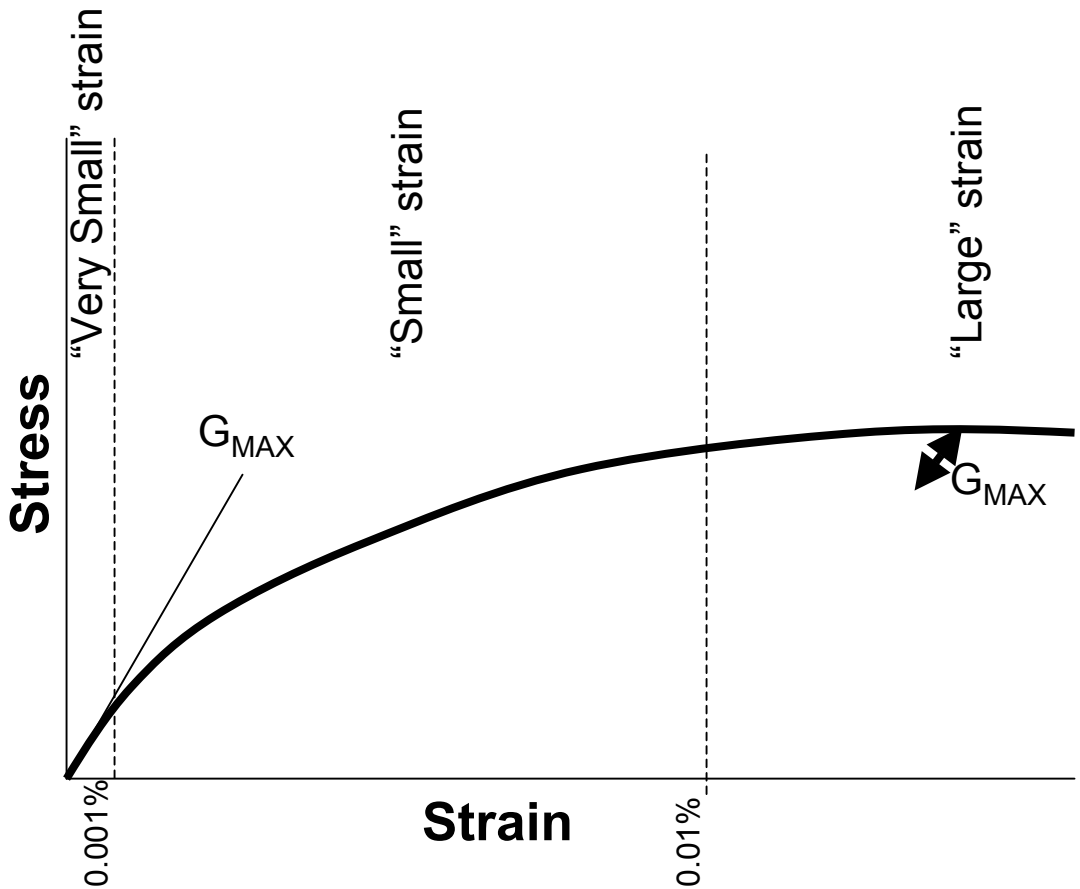
Example Moisture-Modulus Curve



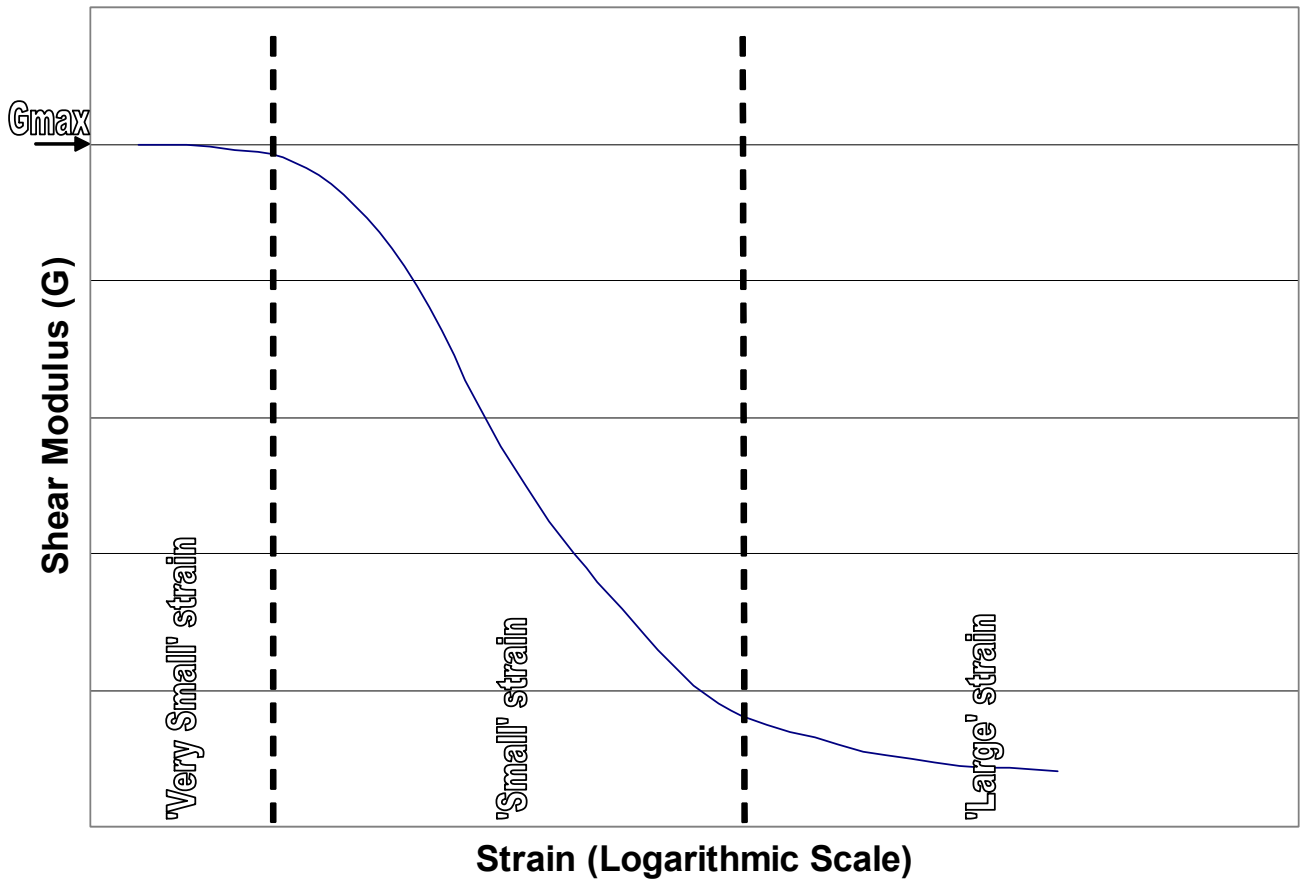
Strain Level

- The shear modulus (G) varies with the amount of strain applied during measurement
- Three distinct strain levels: ‘very small’, ‘small’, and ‘large’
- Bender elements test only within the ‘very small’ zone, therefore, they record G_{MAX}

Strain Level



Strain Level



Other Issues

- Aging (Volumetric Creep) Phenomenon
- Identification of the shear wave arrival time (near field effect)
  - Compression waves move more quickly
  - Analytical solution proposed by Sanches-Salinero et al.
  - Do not use square pulses (one frequency only)

Future Work

- Build a bender element into the top cap and base pedestal of a triaxial cell
- Measure M_r and G_{max} simultaneously for a variety of samples
- Construct a useful relationship between them

Any Questions?