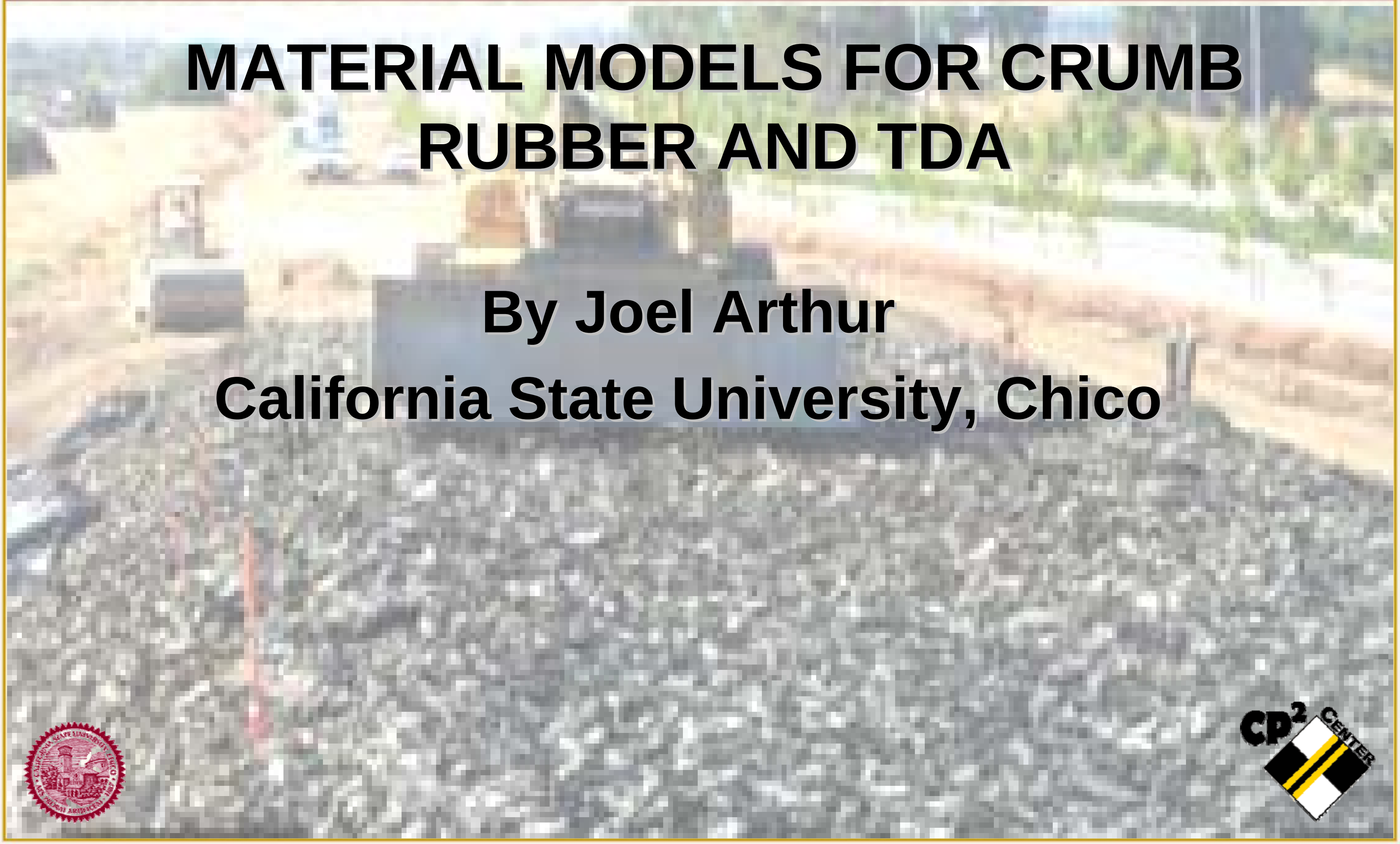
Today decides tomorrow!!!



MATERIAL MODELS FOR CRUMB RUBBER AND TDA

By Joel Arthur

California State University, Chico

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 Characteristics
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
  - “Cohesionless”
  - 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**

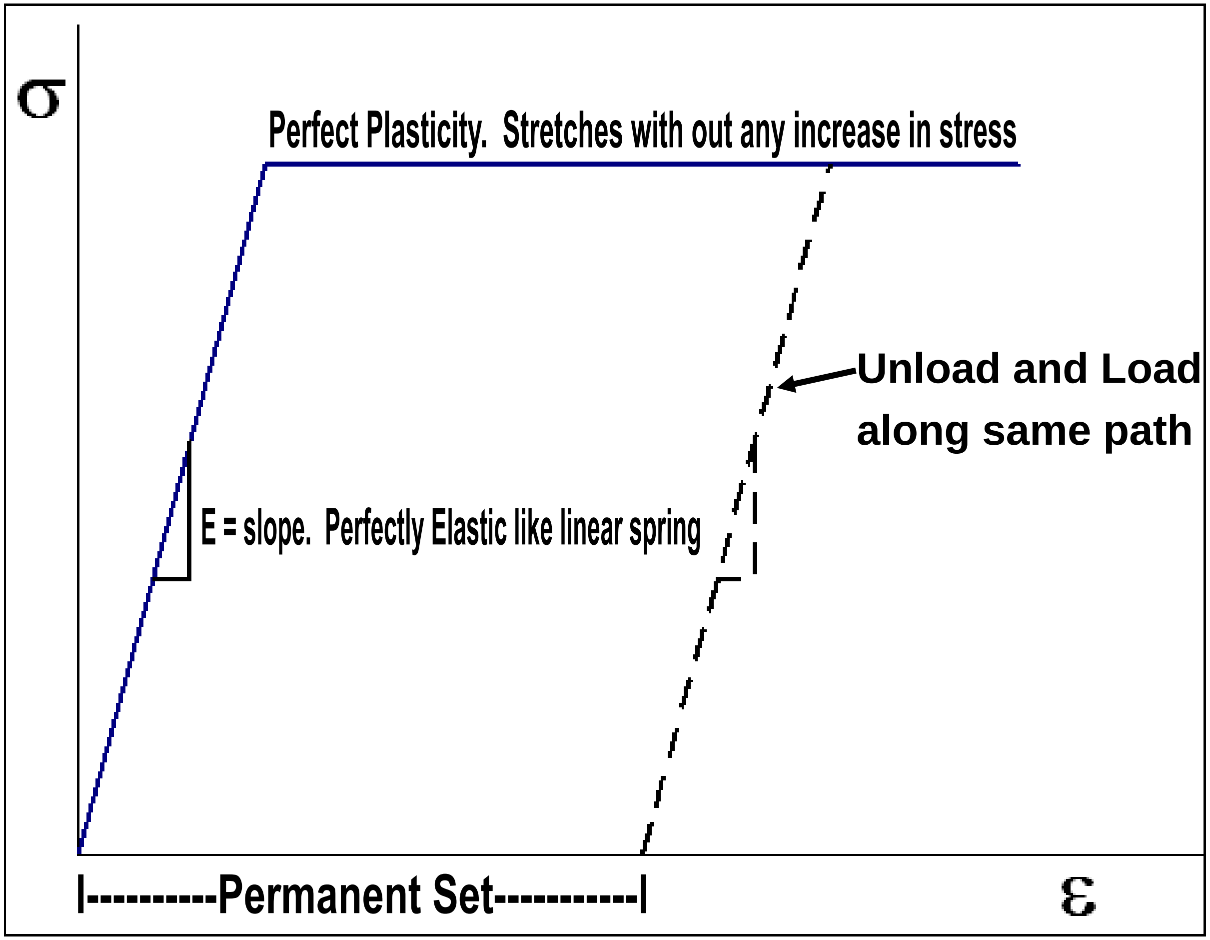
TDA STRENGTH

TDA can support compressive but not tensile stresses and typically fails in shear

The Shear Strength of TDA is affected by five factors:

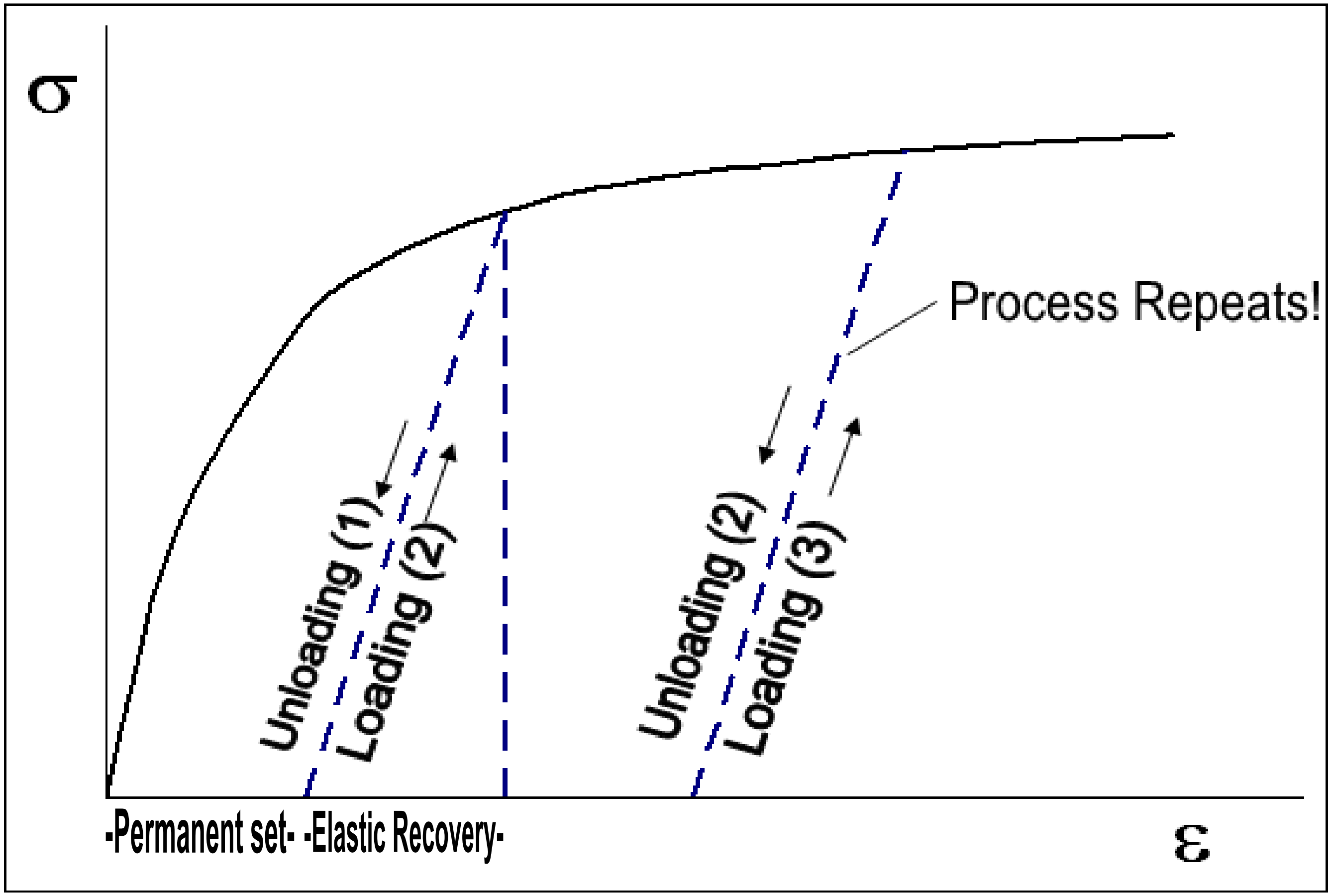
1. Size and shape of the tire shreds
2. The density (packing) of the sample at the beginning of the test
3. Magnitude of the compressive normal loading
4. The orientation of the tire shreds in the specimen
5. “Cohesion”

Material Model: Elastoplastic



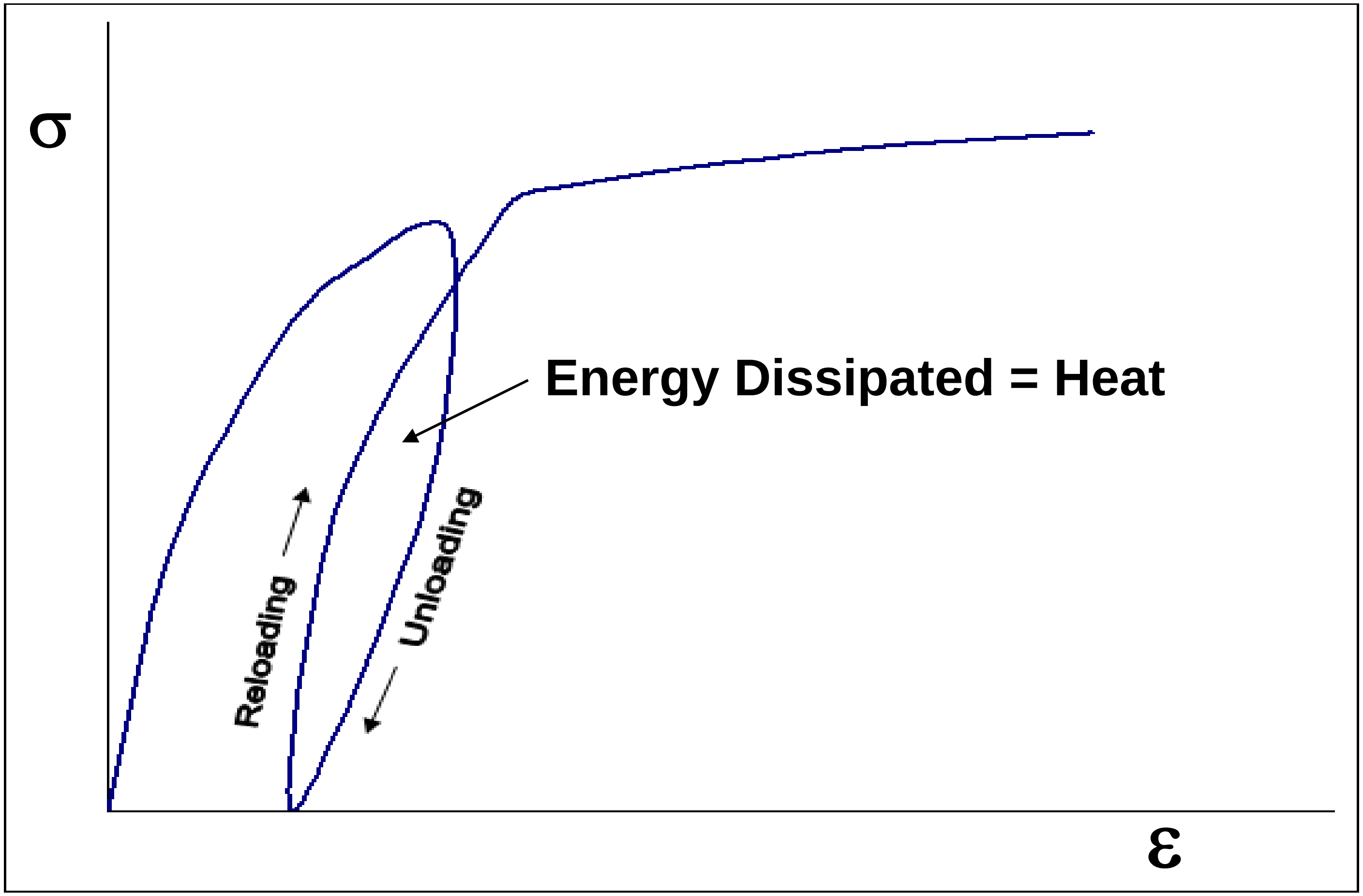
More General Material Model

Nonlinear Inelastic Model



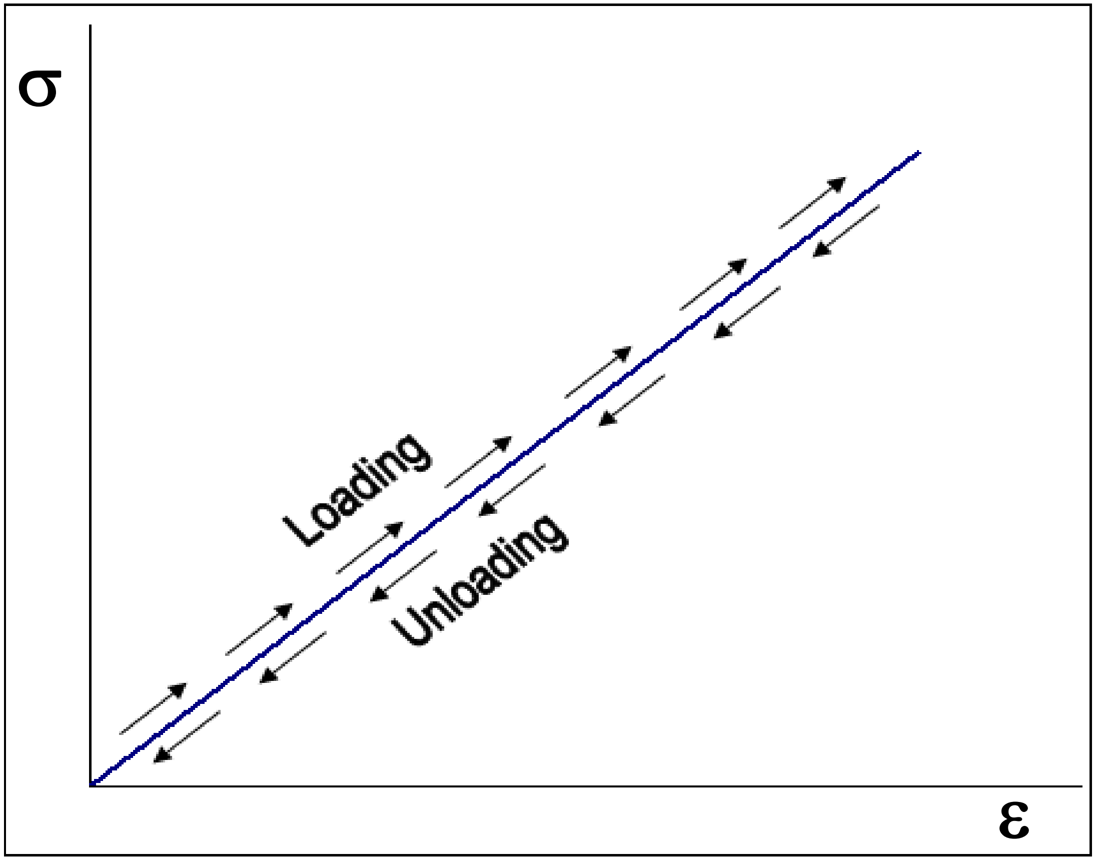
More Realistic General Model

Energy is lost in unloading and reloading process (hysteresis)



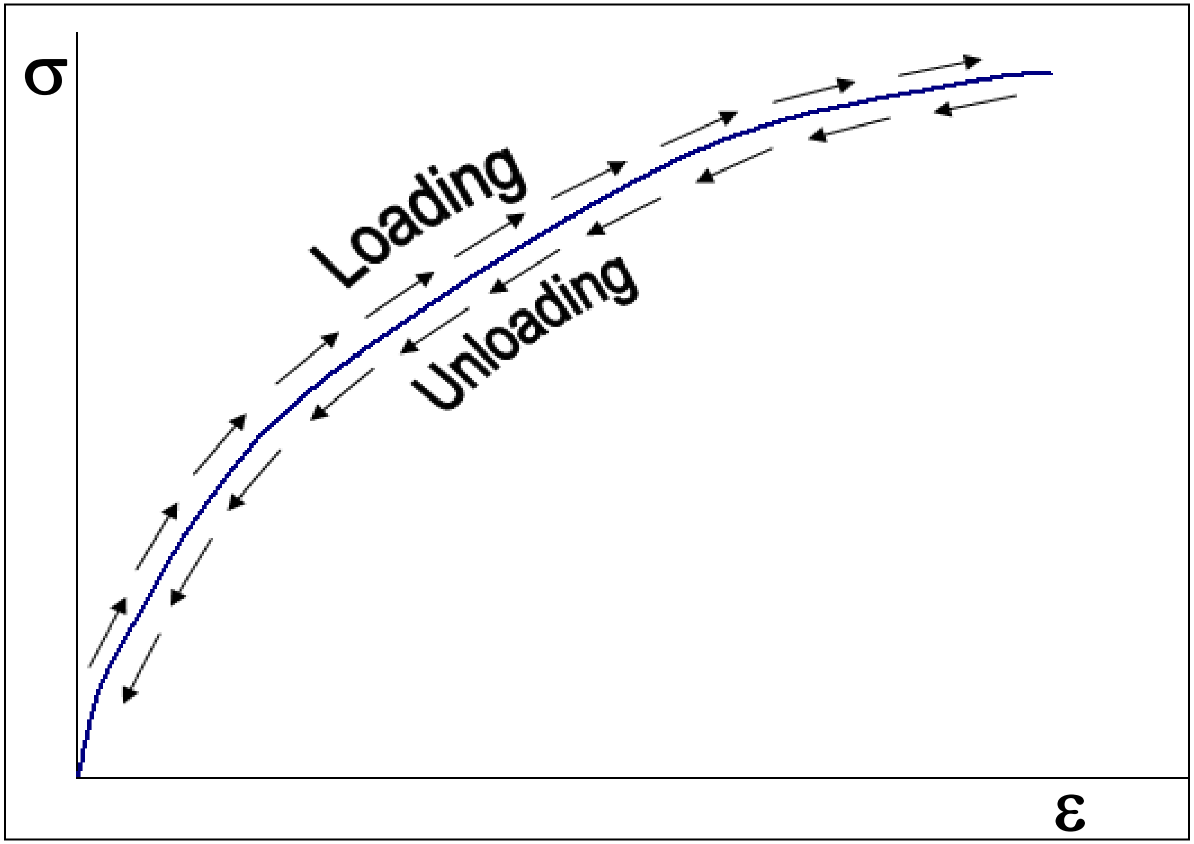
Closer Look at Elasticity

- Linear Elastic Behavior- makes things easy
- True up to Elastic Limit



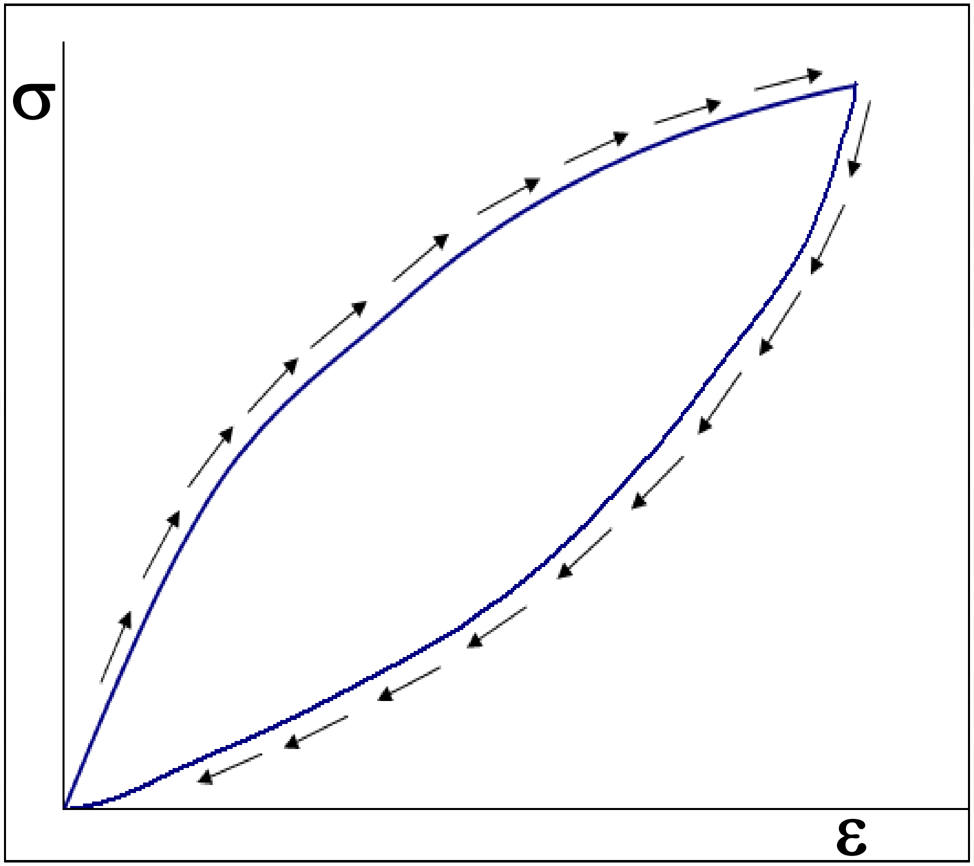
Non-Linear Elastic (Rubber)

- Nonlinear load path
- Still loads and unloads along same path



Anelastic Behavior

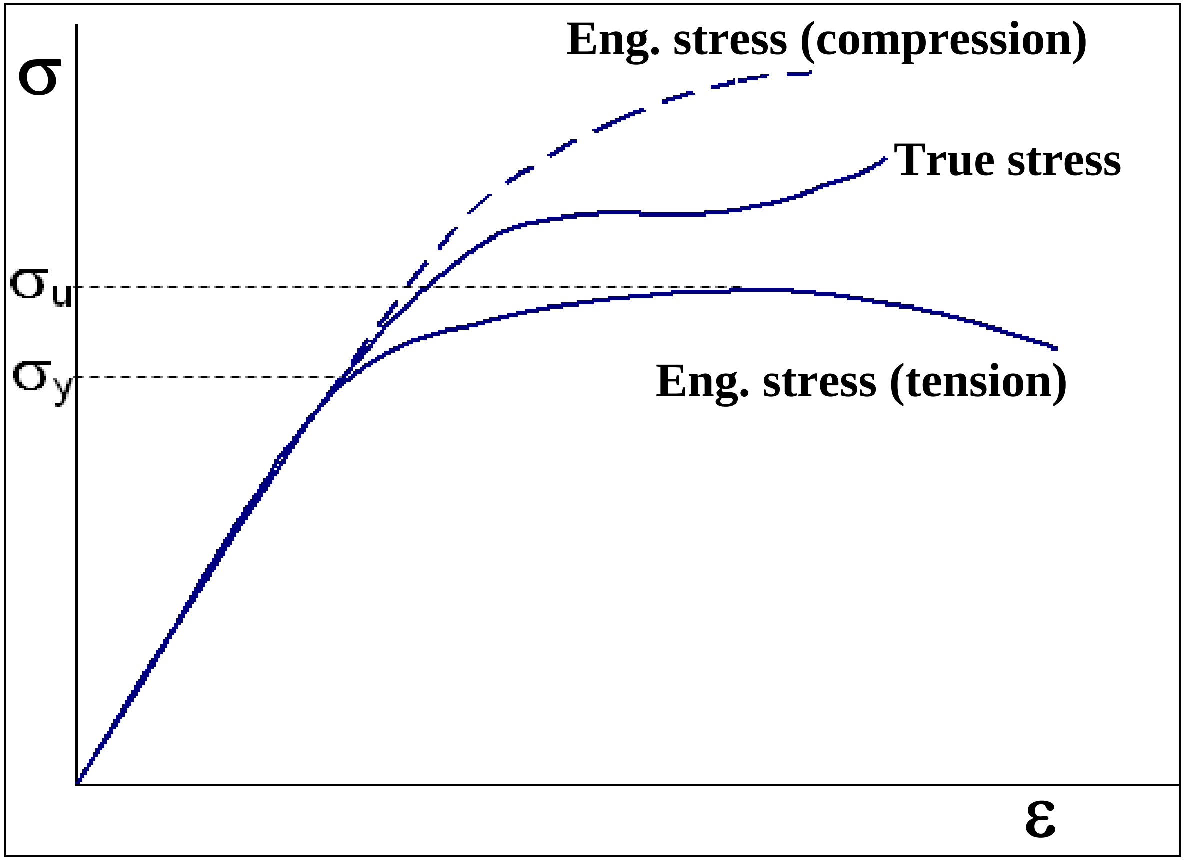
- Does not load and unload along the same path
- Thermal energy- Dissipates to the surroundings without damaging material
- Useful for vibration damping
- Examples
  - Mounts for motors and other rotating machinery
  - Subbase under railroads (TDA application)



- Just think about applications for earthquakes if we could get concrete to behave this way by adding waste tire rubber

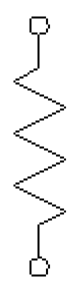
Poisson Effect

- After Yielding, values of engineering and true stress deviate appreciably



Possible Material Models

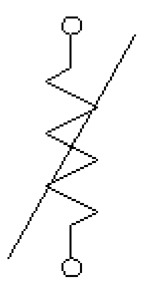
- **Hookean**



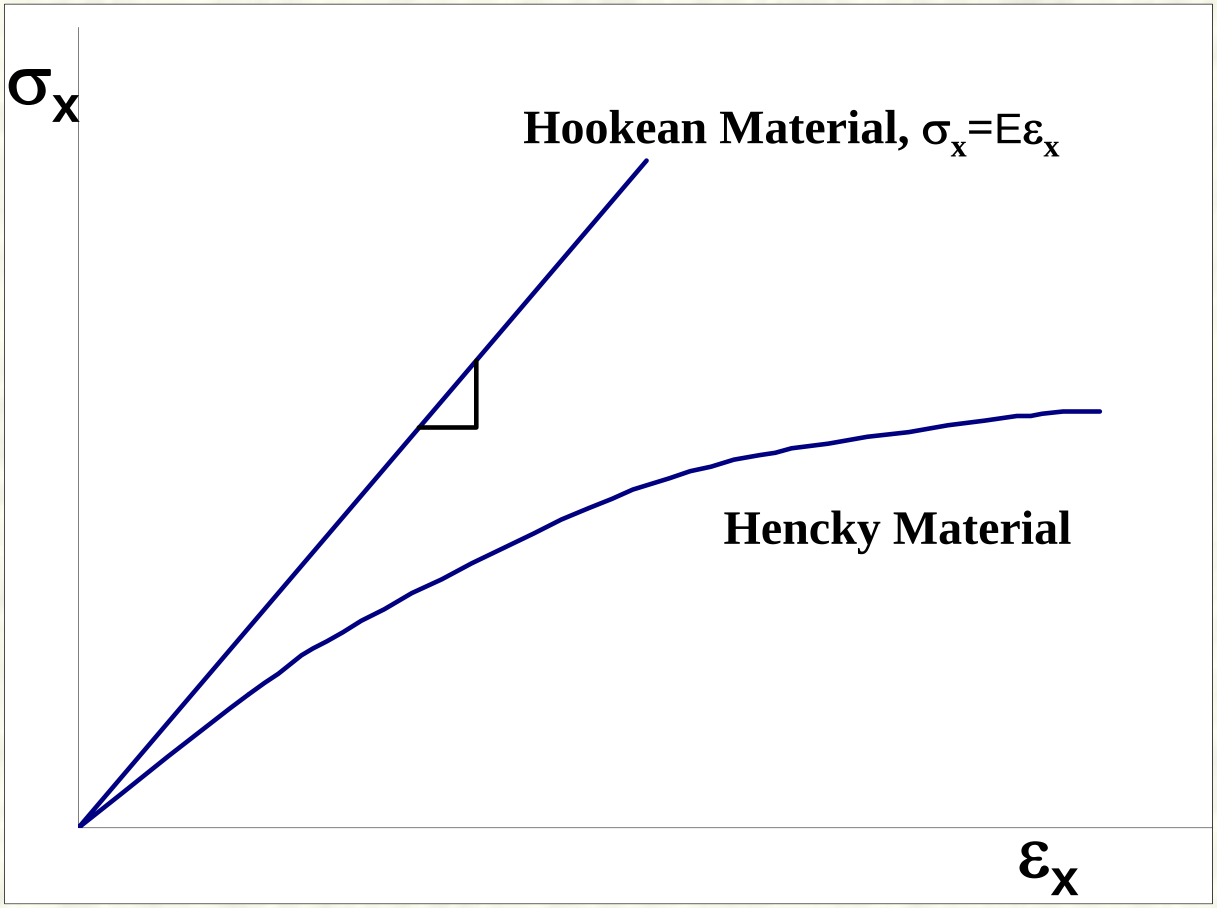
Linear Elastic

E = Spring Constant

- **Hencky Material**



Nonlinear Spring



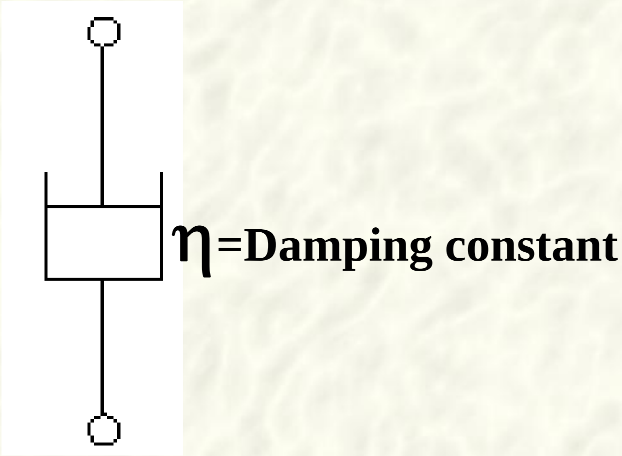
In either case, energy is conserved if Loading and Unloading curves coincide

Viscous Materials

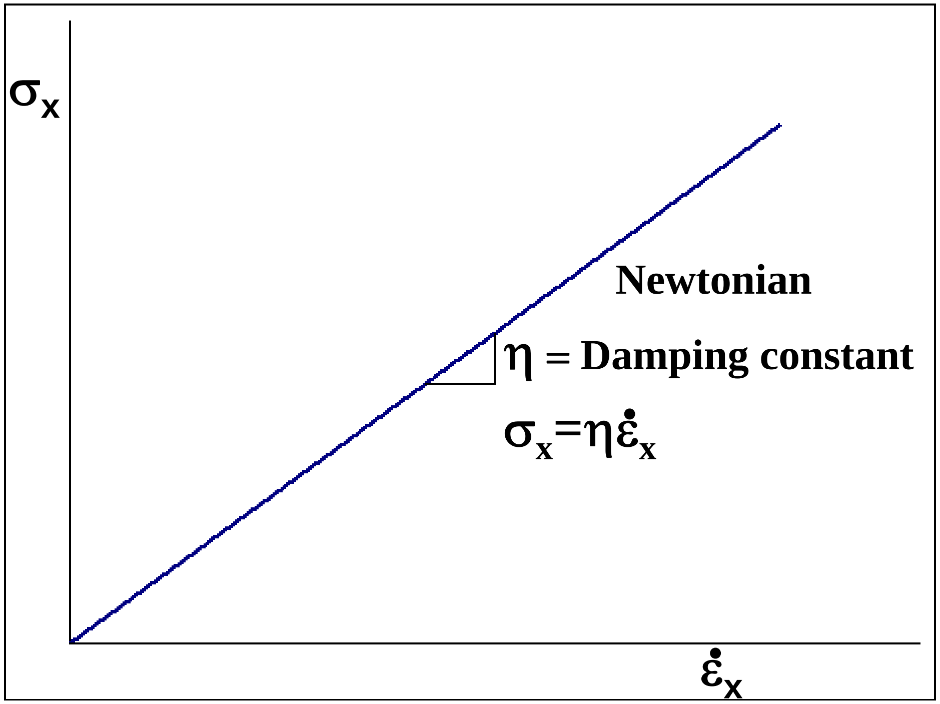
- Named viscous because of fluid-like behavior
- Material is viscous if stress determines strain *rate*
- i.e. strain rate is a function of stress
  - $d\varepsilon/dt = \dot{\varepsilon}_x = g(\sigma_x)$
- Strain is *not* recovered upon removal of stress

Viscous Materials

- If stress is a linear function of the strain rate, then we call it a Newtonian fluid.
  - Use linear dashpot to model behavior:



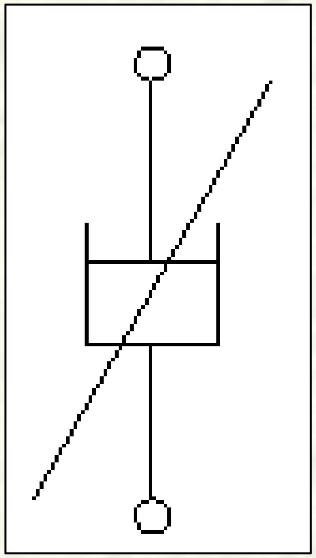
Ideal Viscous (Newtonian)



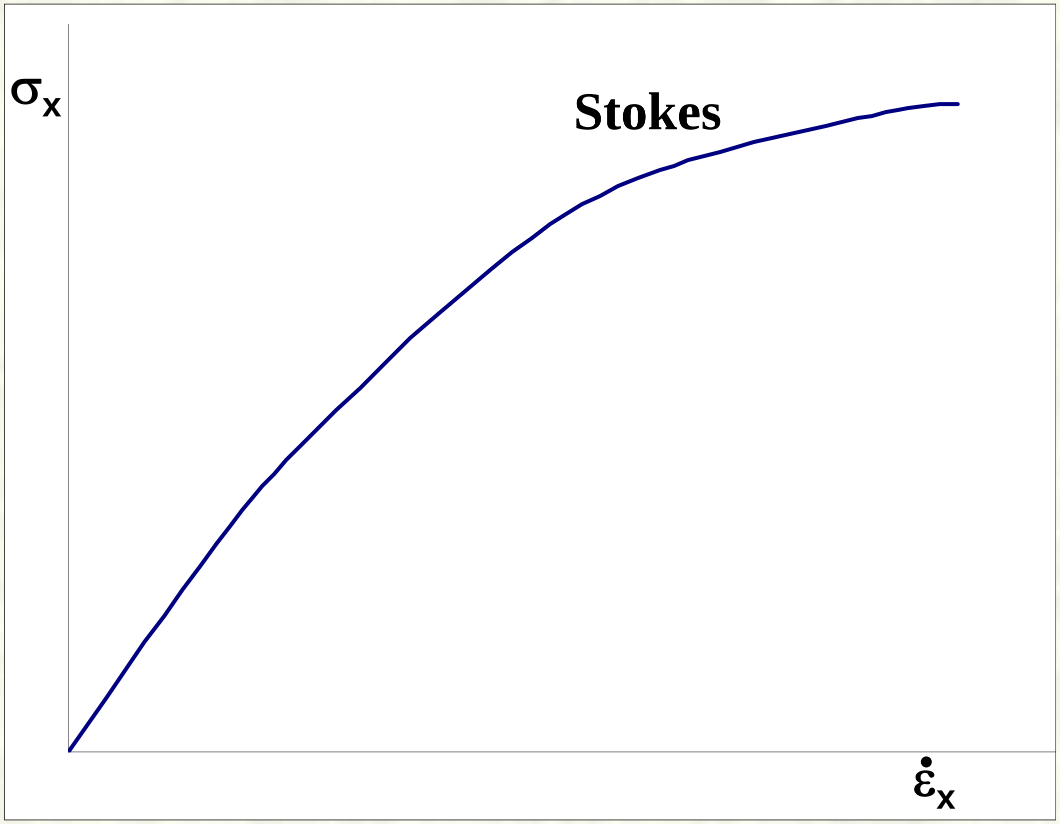
- In this model, we consider σ_x to be the force on the system while $\dot{\varepsilon}_x$ is the speed of the piston. Therefore η = Damping constant

When Force and Speed are Not Linearly Related

- We have a Non-Newtonian or Quasi-Viscous case.
- Also referred to as a “Stoke’s” Material



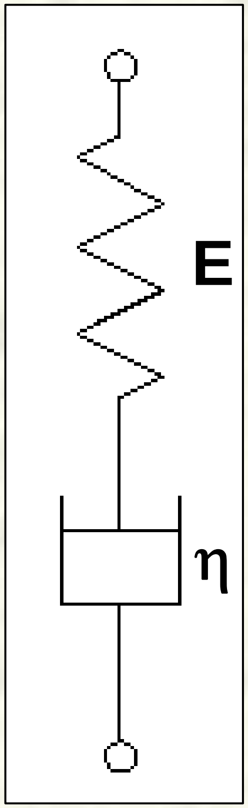
Quasi-viscous
(Stokes)



Viscoelastic Materials

- Materials that posses viscous and elastic properties
- Many materials are viscoelastic
  - Examples:
    - Structural Metals and Rock at high temperatures
    - Plastics at room temperature
- Use *combinations* of springs and dashpots to model viscoelastic materials

Linear Maxwell Model



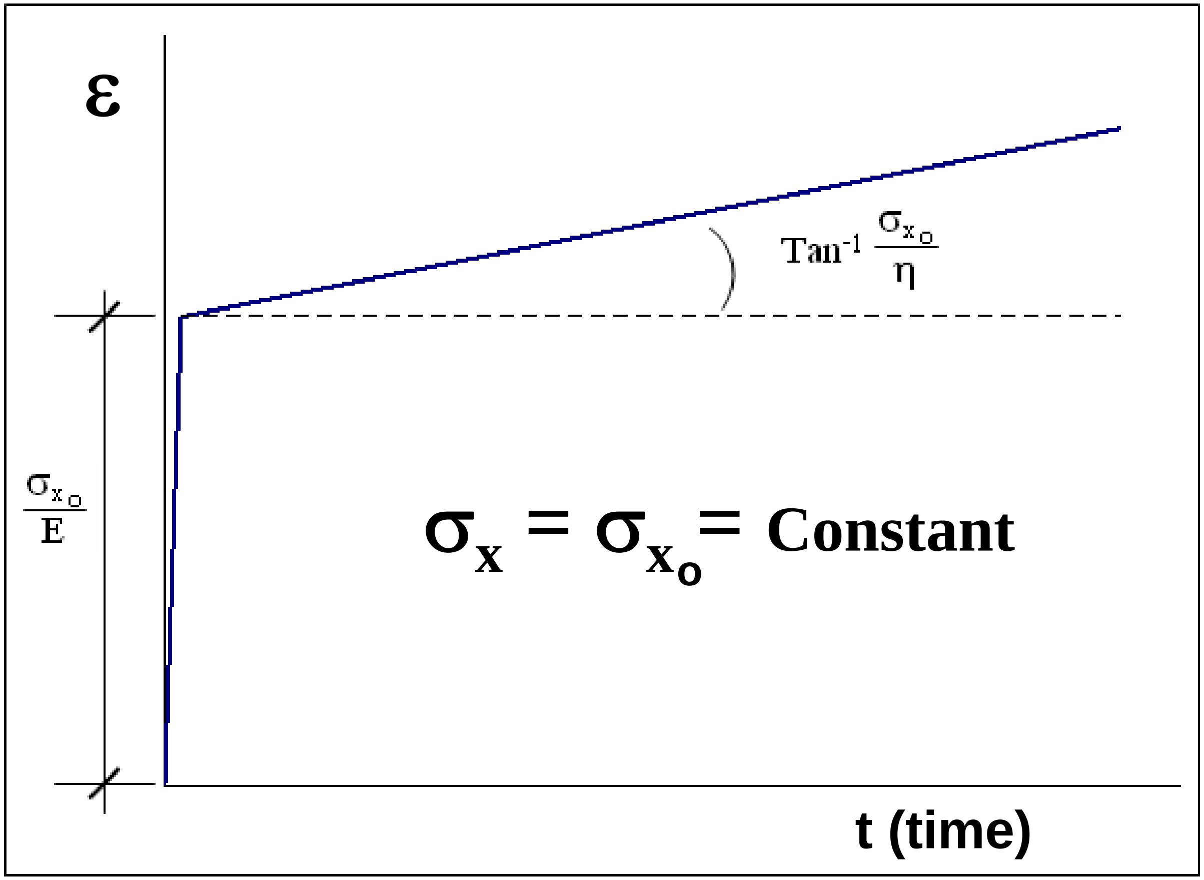
- Linear spring and dashpot in series, therefore $F_{spring}=F_{dashpot}$
- Strain rate composed of two parts
  1. Strain rate in spring, $\dot{\varepsilon}_x=\dot{\sigma}_x/E$
  2. Strain rate in dashpot, $\dot{\varepsilon}_x=\sigma_x/\eta$

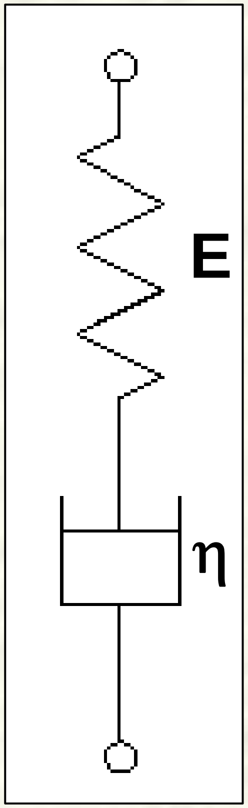
- Add them using superposition to get total strain rate of system

$$\boxed{\dot{\varepsilon}_x=\dot{\sigma}_x/E + \sigma_x/\eta}$$

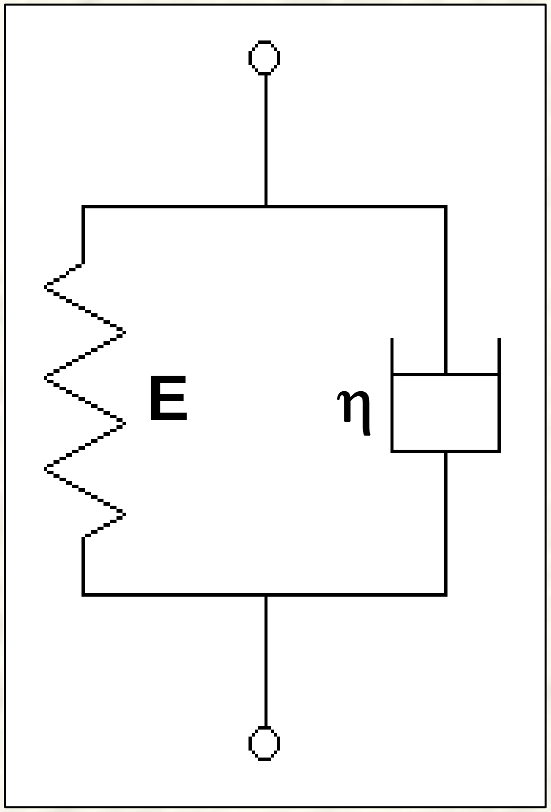
Graphical Linear Maxwell Model – Constant Stress

- **Constant stress gives a nearly instantaneous spring displacement plus a constant strain-rate from the dashpot**





Kelvin Model



- Spring and dashpot are in parallel
- Strains are equal, but forces are not
- Stress components:

$\sigma_{spring} = E\varepsilon_x$

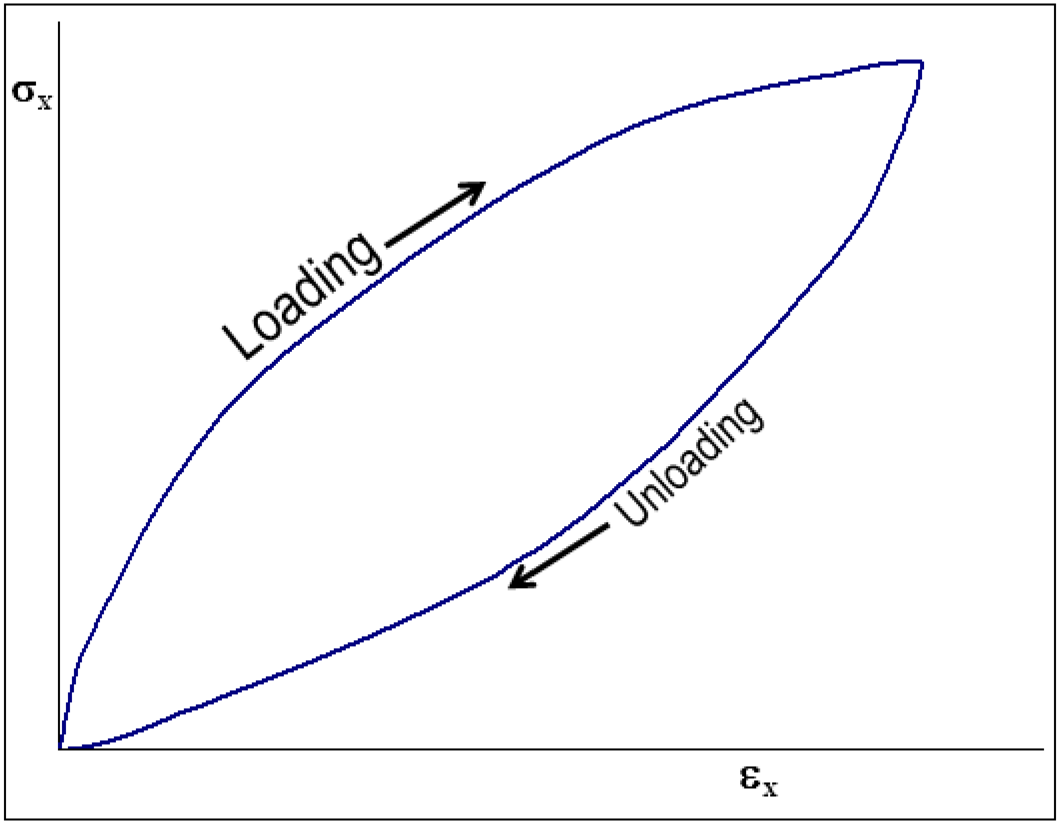
$\sigma_{dashpot} = \eta\dot{\varepsilon}_x$

Therefore, by superposition

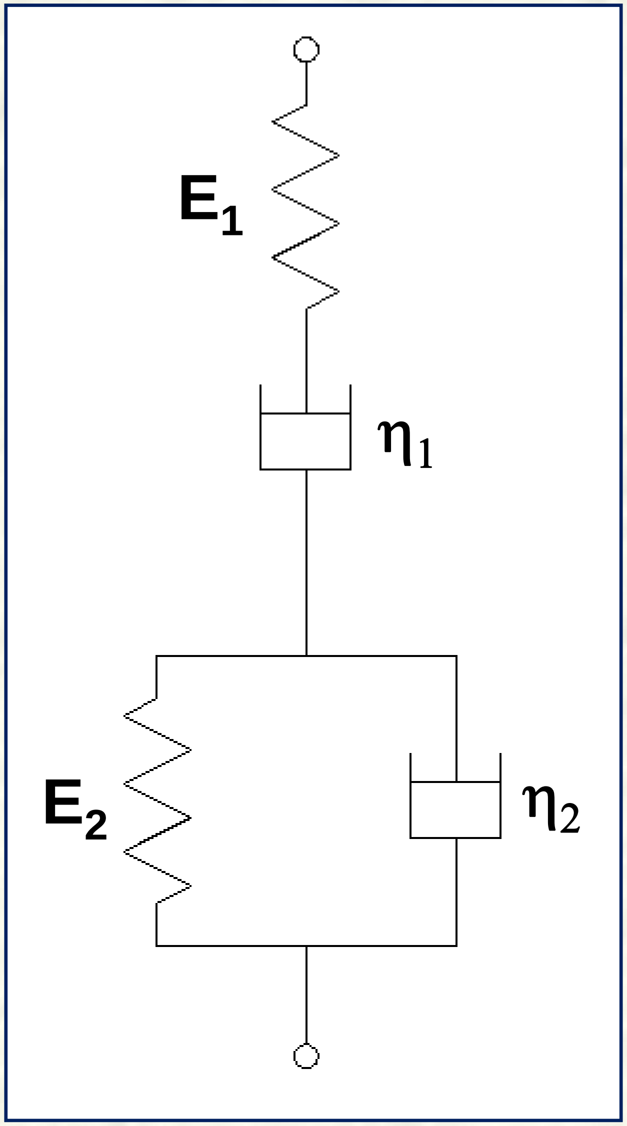
$$\boxed{\sigma_{total} = E\varepsilon_x + \eta\dot{\varepsilon}_x}$$

Kelvin Relaxation

- When the spring relaxes, energy is dissipated in the dashpot

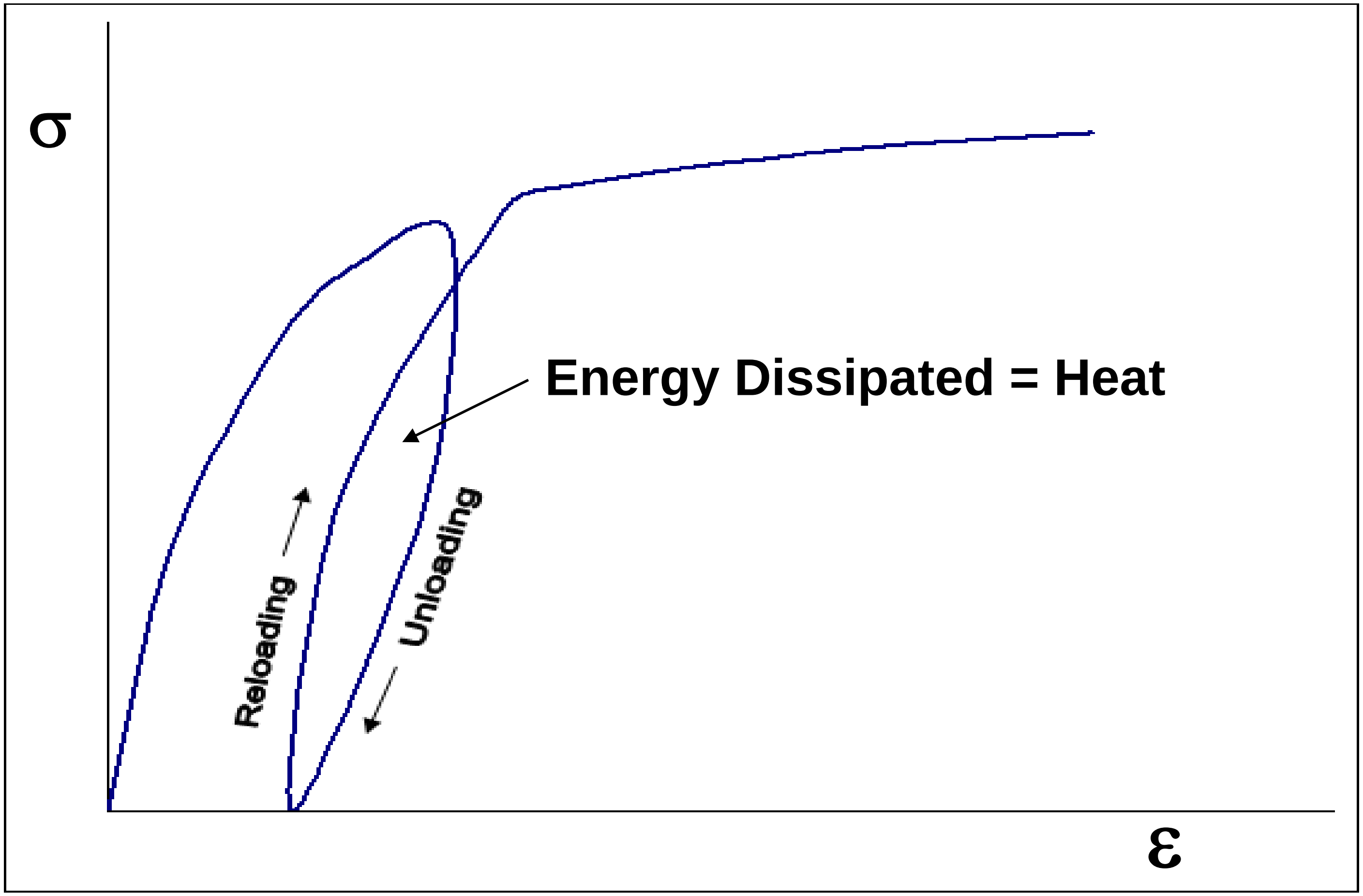


More General Model (Burgers Fluid)

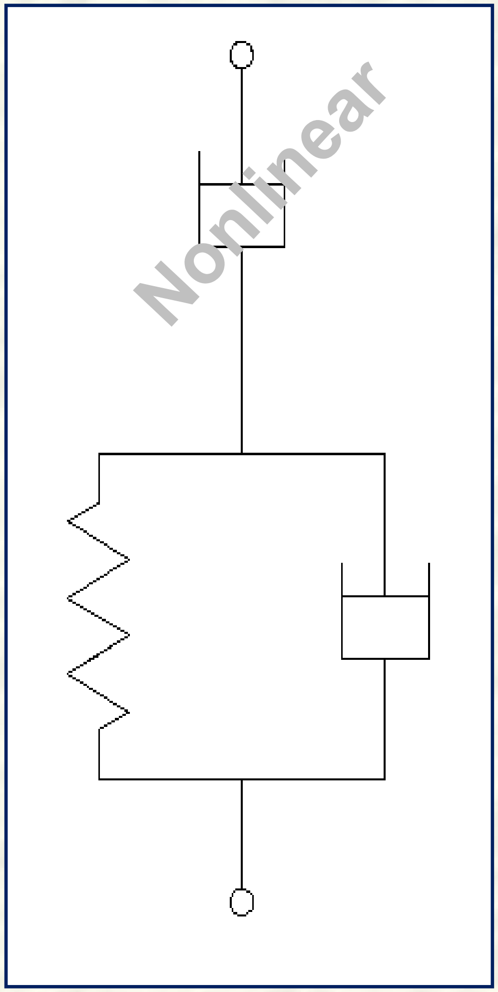


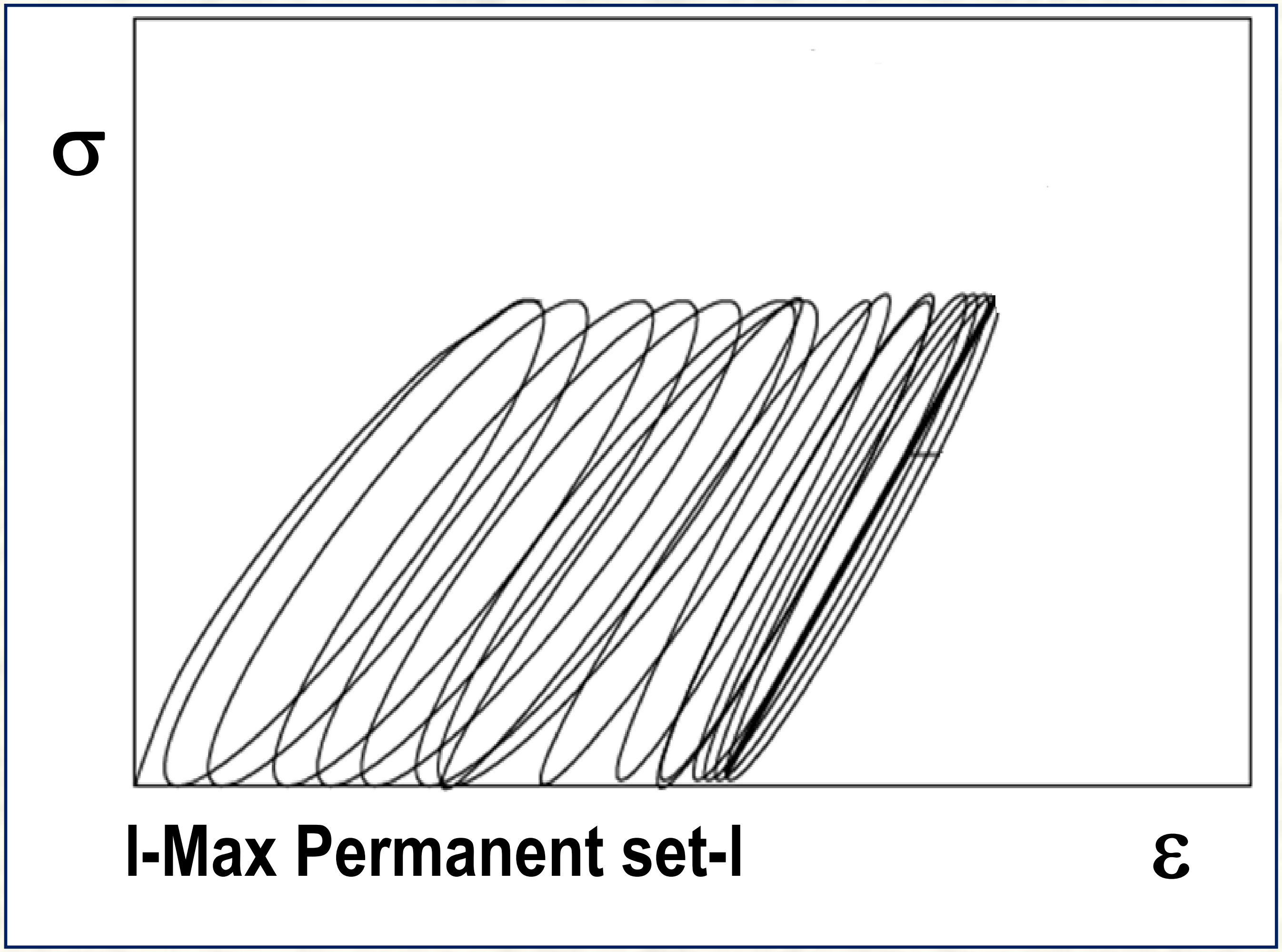
- Combine Maxwell and Kelvin model in Series
  - Some permanent deformation
  - Some perfect elasticity
  - Some vibration damping
- Many additional spring-dashpot combinations possible

General Model Behavior



General Model- Kelvin Model in Series with Nonlinear Dashpot





Potential Applications

- Energy Dissipation
  - Earthquake Energy Absorption
- Vibration Mitigation
  - Machinery Mounts
  - Train and Truck Traffic Loads

Vibration Mitigation Application- Vasona Light Rail Line and Test Track

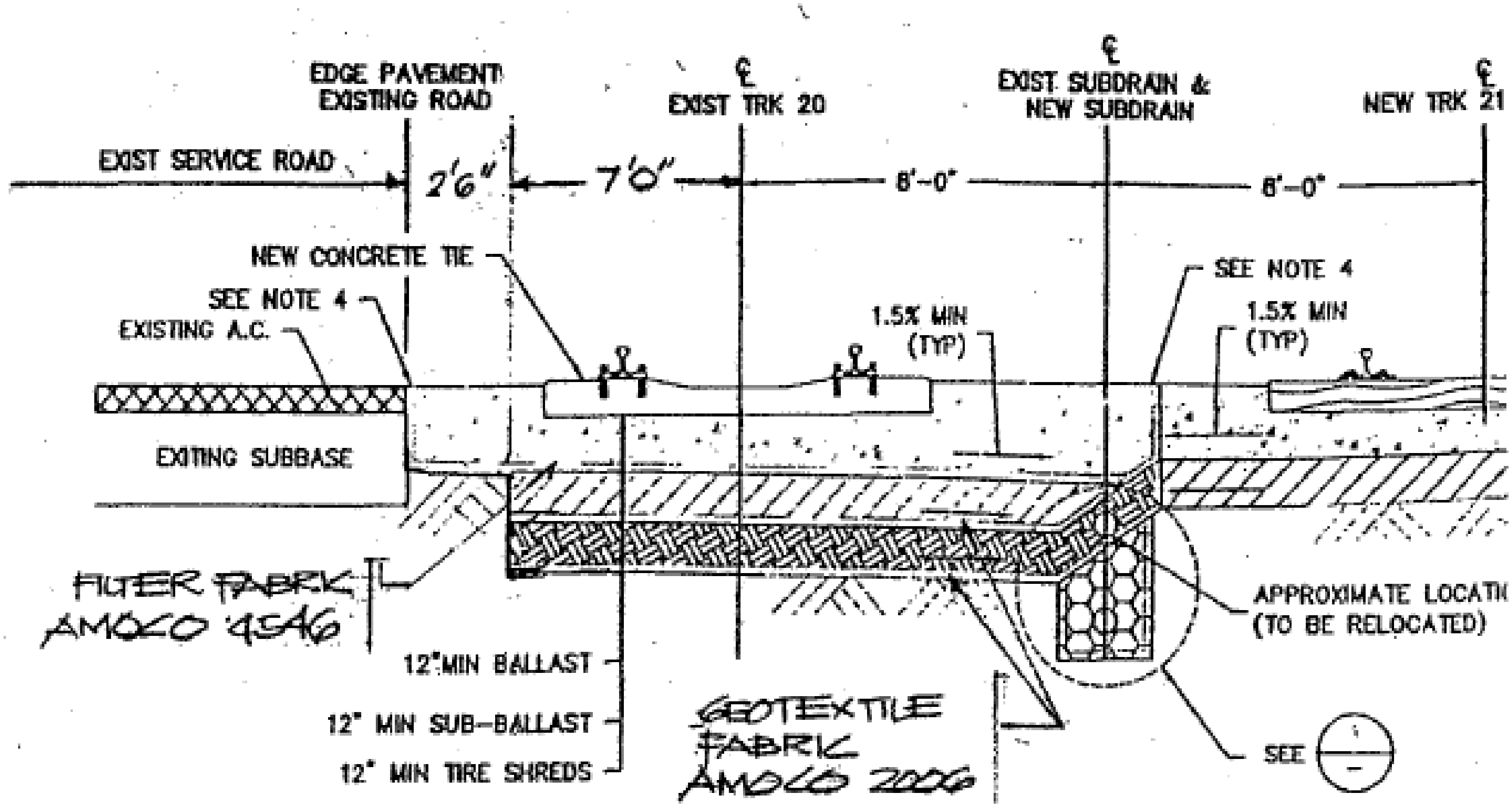
- TDA used as subbase beneath train track ballast

- Goal: Reduce vibration for local residence and businesses

Case History VTA Light Rail Project

- Reduce ground borne vibrations that affect adjacent businesses and residences
- 12” of Type A Tire Shreds below 12” of subballast and 12” of ballast for 1591 feet of track
- Tests indicated a significant reduction in vibration with TDA section

Test Track Cross-Section



Cross section of tire shred test section.

TDA Test Track Construction

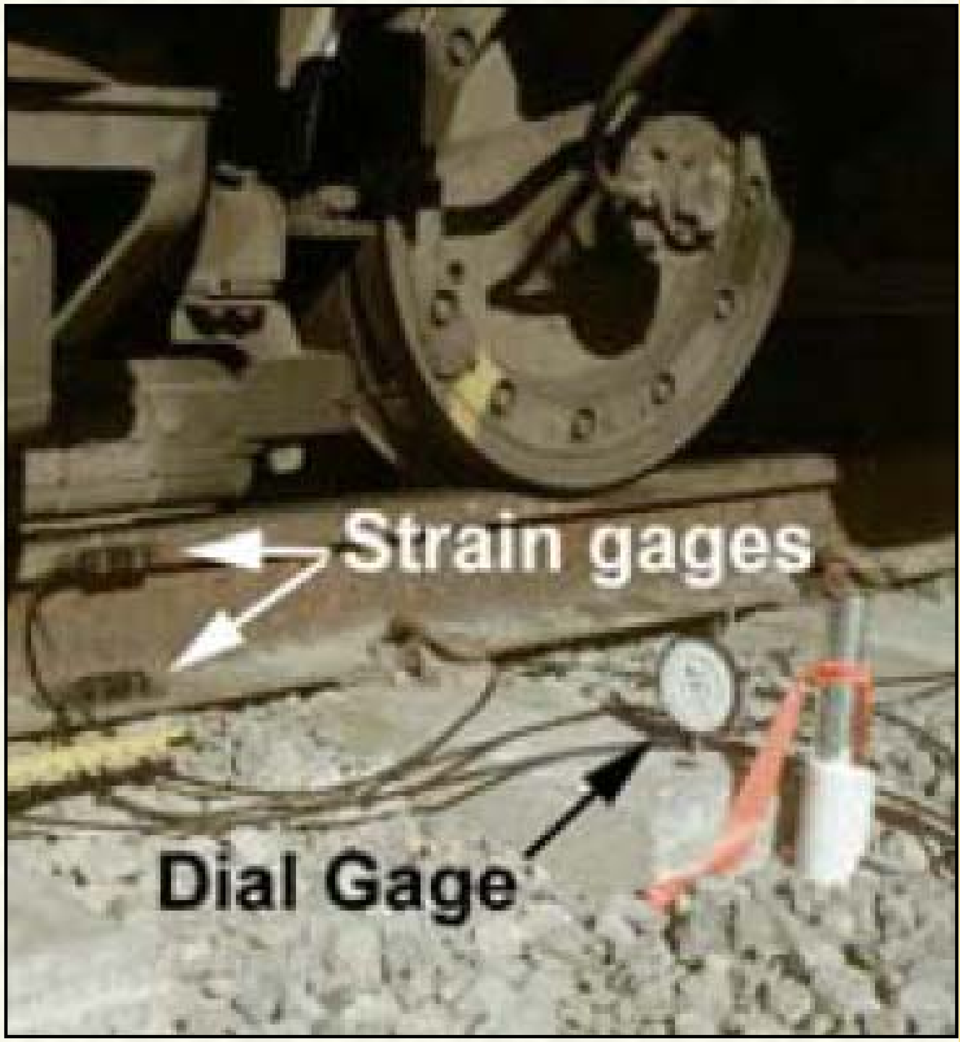
Test Track Construction

Finished Test Track

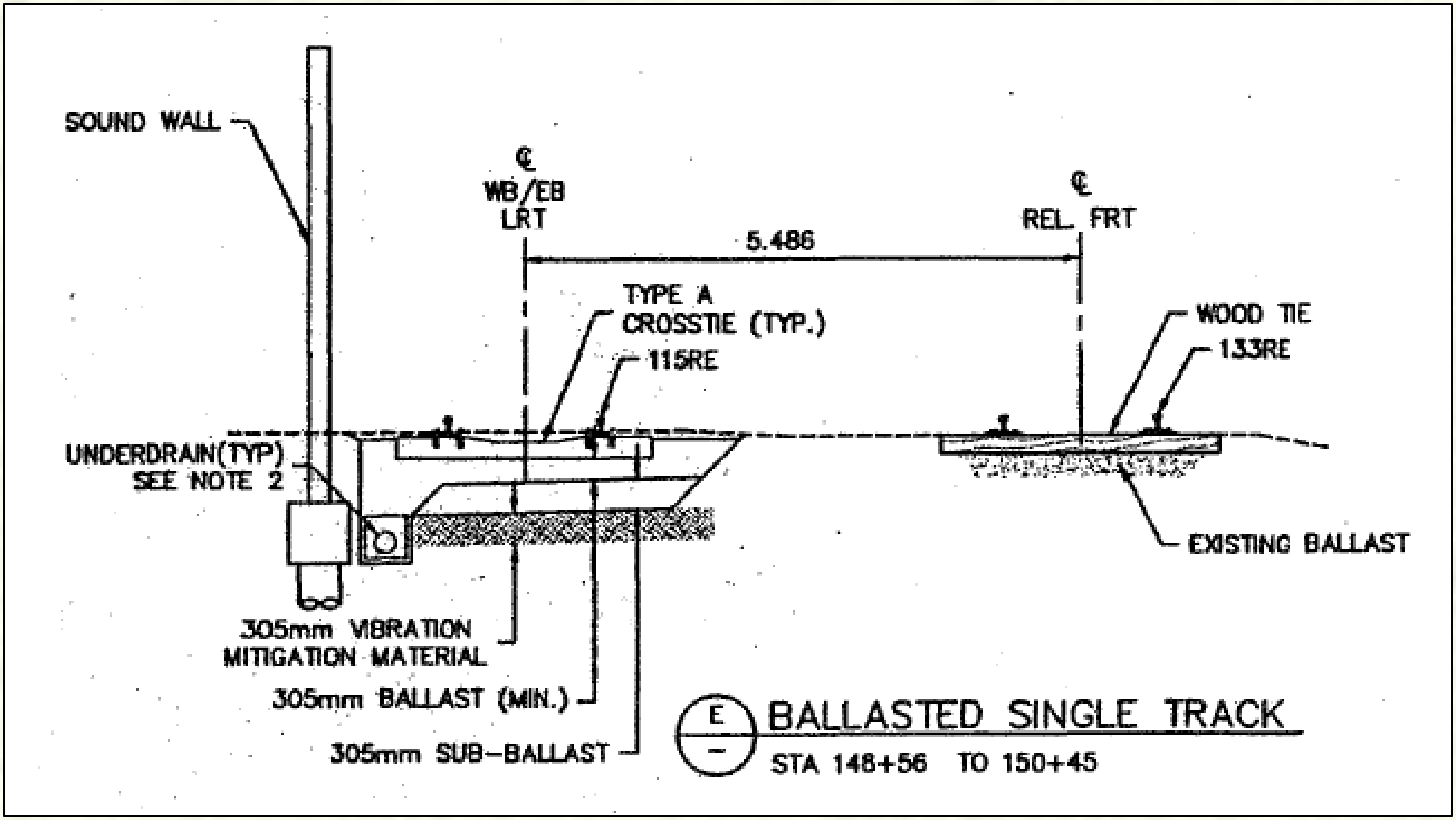
Vibration Sensor Mounted Under Ground

Measuring Devices

- Strain gages to measure strains in rail
- Dial gage to measure deflections

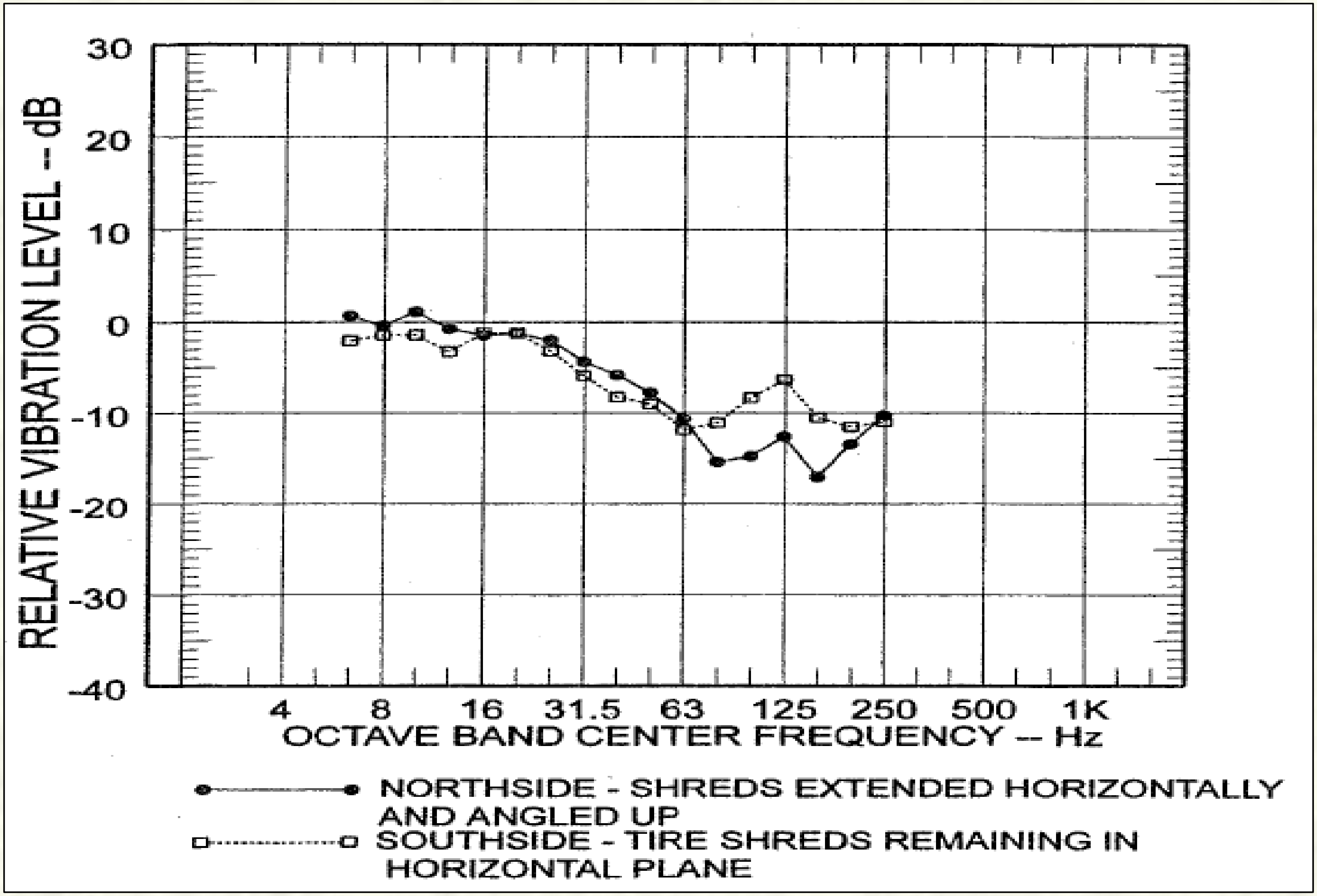


Rail Line Cross Section Drawing



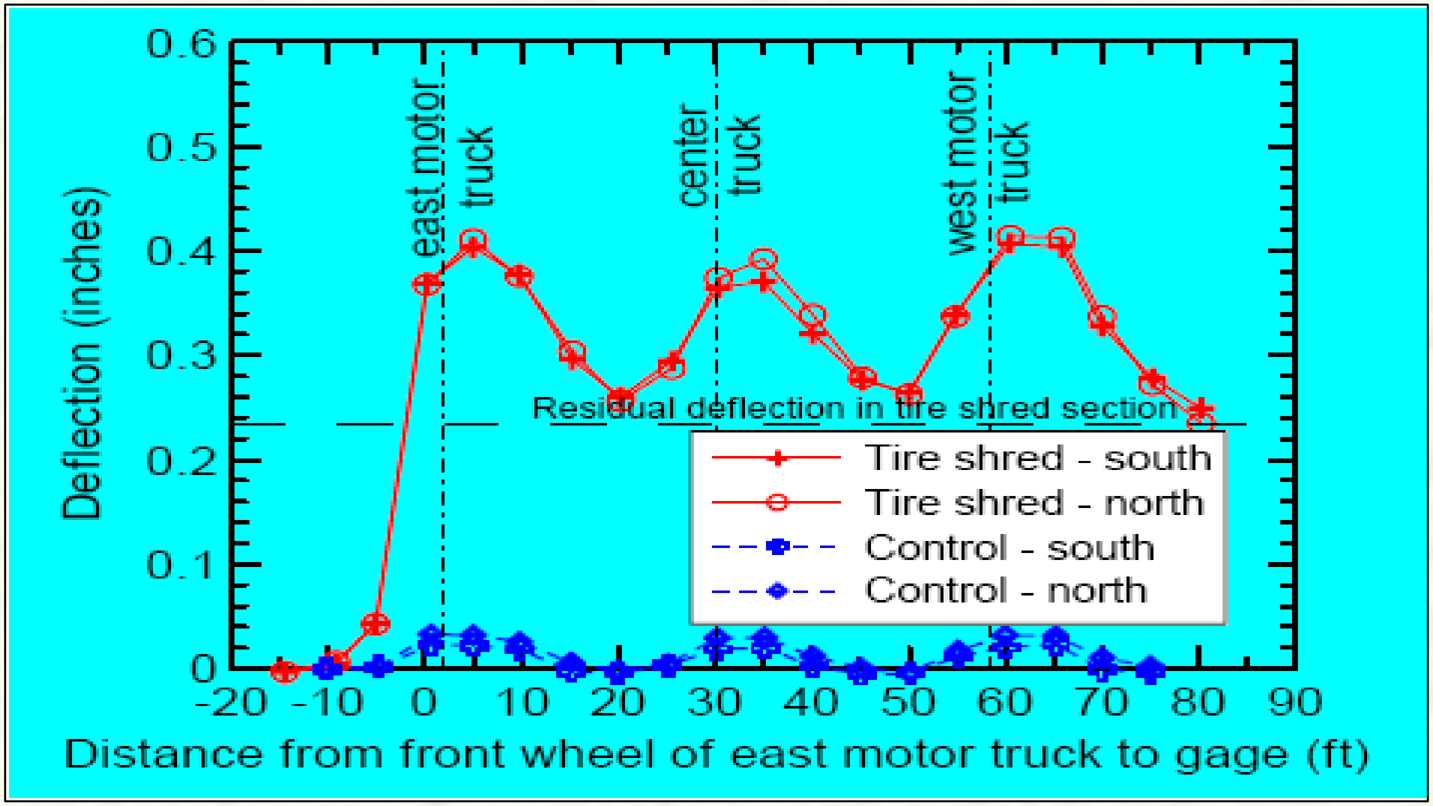
Rail Line Construction Pictures

Results - Vibration



Tie Deflections

- Elastic Deflections in ties less than 0.2 in. Which is acceptable
- Minor permanent deflection may mean more frequent releveling of the ties.



Cost Savings

- Cost of conventional track = $100 per track-ft
- Cost of track with TDA vibration mitigation = $121 per track-ft
- Cost of floating slab vibration mitigation = $600-1000 per track-ft
- Cost savings = $479-$879 per track-ft
- Total savings = $1 to $2-million

Summary

- Presented practical material models applicable to TDA for vibration mitigation
- TDA can save money in these applications
- More data and studies are needed to calibrate these material models

Crumb Rubber Concrete

California State University, Chico

Has Many Names in the Literature

- Crumb Rubber Concrete (CRC)
- Rubber Included Concrete (RIC)
- Rubberized Concrete
- Rubcrete
- Tire Rubber-Filled Concrete

Potential Effects of Adding Rubber to Concrete

- Reduces Compressive Strength
- Can Increase Ductility
- Increases Toughness (ability to absorb energy)
- May Reduce Cracking
- Reduces Unit Weight of the Concrete
- Reduces Thermal Expansion/Contraction
- May Replace Air Entraining Agent in Cold Environments
- Improves Insulation (but Decreases Thermal Mass)
- Reduces Sound Transmission

Potential Applications of Rubber Included Concrete

- Tire rubber may replace air entraining in cold weather applications
- RIC may be more flexible and crack resistant for light weight paving
- RIC may provide vibration damping and sound transmission mitigation

Mix Design

The mix design should be based on an absolute <u>volume</u> method, replacing mineral aggregate with tire particles of similar size characteristics (gradation). This is accomplished by utilizing the specific gravity of the aggregates.

Mix Design Parameters - RIC

- Type of Rubber Particles
- Size of Rubber Particles and Aggregate
- Gradation of Rubber Particles
- Specific Gravity of Rubber Particles
- Fineness Modulus (Fine Aggregate)
- Rubber Content for Mix
- Water-Cement Ratio

Crumb Rubber Sample

Tire Buffings Sample

Sample of Mix Designs from Literature

Author	Rubber Type	Rubber Content	Method of Mix Design
Kaloush et. al.	1mm Crumb Rubber	0, 50, 100, 150, 200, and 300 #/cuyd	Replaced fine aggregate with crumb rubber by weight, increased w/c ratio
Fedroff et. al.	Super fine powder	0, 10, 20, and 30%	By weight of cement in mix adjusted w/c ratio to get 3 to 5 inches of slump
Tantala et.al.	Buff Rubber	5 and 10%	Replaced 5% and 10% of coarse aggregate with buff rubber by volume
Li et. al.	Cyrogenic Ground Rubber<2mm	33%	Replaced 33% of fine aggregate by volume
Schimizze et.al.	Fine/Coarse Reclaimed Rubber	5% of mix design by weight	Lowered both 1. fine aggregate and 2. fine and coarse aggregate to get 5% rubber by weight
Biel and Lee	3/8" minus rubber droppings	0 to 90% in 15% increments	Replaced fine aggregate with crumb rubber by volume gave 0 to 25% rubber by volume in mix
Eldin et.al.	Ground tire chips, fine crumb rubber	0,25,50,75,100% by volume	Test specimens replacing either coarse or fine aggregate

Difficulties Interpreting Literature Results

- Different types of tire particles
- Different methods of mix design
- Different pretreatment of tire particles
- Different testing procedures

Only general conclusions can be drawn from the results published in the literature!

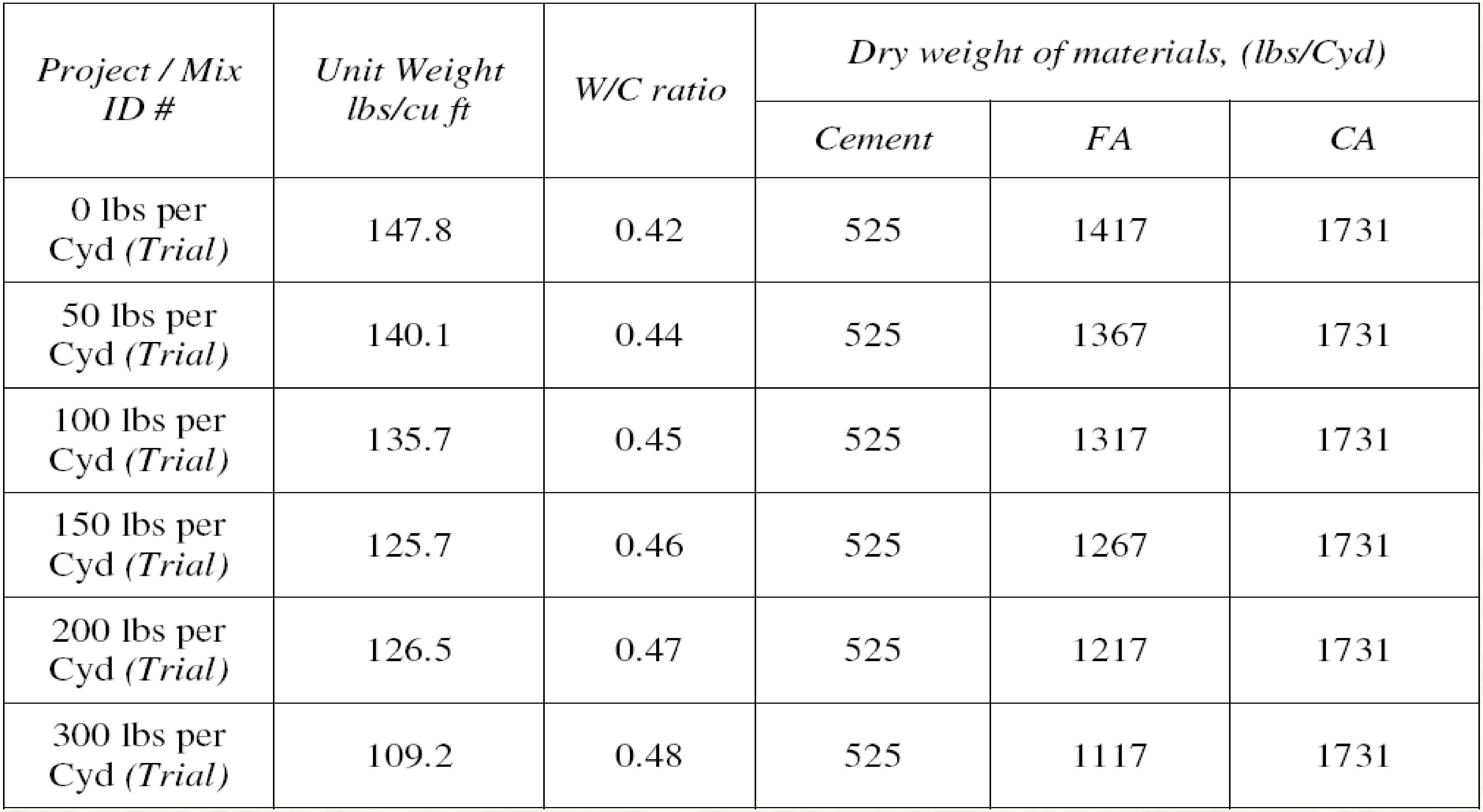
Summary of Engineering Properties of Rubberized Concrete from the Literature

- Compressive Strength
- Tensile (Split Cylinder) Strength
- Flexural (Modulus of Rupture) Strength
- Unit Weight
- Air Content
- Stiffness
- Ductility
- Toughness
- Coefficient of Thermal Expansion
- Durability
- Damping characteristics

Rubberized Concrete Compressive Strength

- Rubber is weaker and less rigid than the mineral aggregate that they replace, which reduces the compressive strength
- Increasing rubber content has been found to increase the air content, which also reduces the compressive strength
- The bond characteristics between the cement paste and the rubber may also reduce the compressive strength
- As always, w/c ratio, unit weight, workmanship, and curing affect compressive strength

Mix Ingredients for Crumb Rubber Concrete (Kaloush et. al. 2004)



Project / Mix ID #	*Unit Weight lbs/cu ft*	*W/C ratio*	*Dry weight of materials, (lbs/Cyd)*		
			Cement	*FA*	*CA*
0 lbs per Cyd *(Trial)*	147.8	0.42	525	1417	1731
50 lbs per Cyd *(Trial)*	140.1	0.44	525	1367	1731
100 lbs per Cyd *(Trial)*	135.7	0.45	525	1317	1731
150 lbs per Cyd *(Trial)*	125.7	0.46	525	1267	1731
200 lbs per Cyd *(Trial)*	126.5	0.47	525	1217	1731
300 lbs per Cyd *(Trial)*	109.2	0.48	525	1117	1731

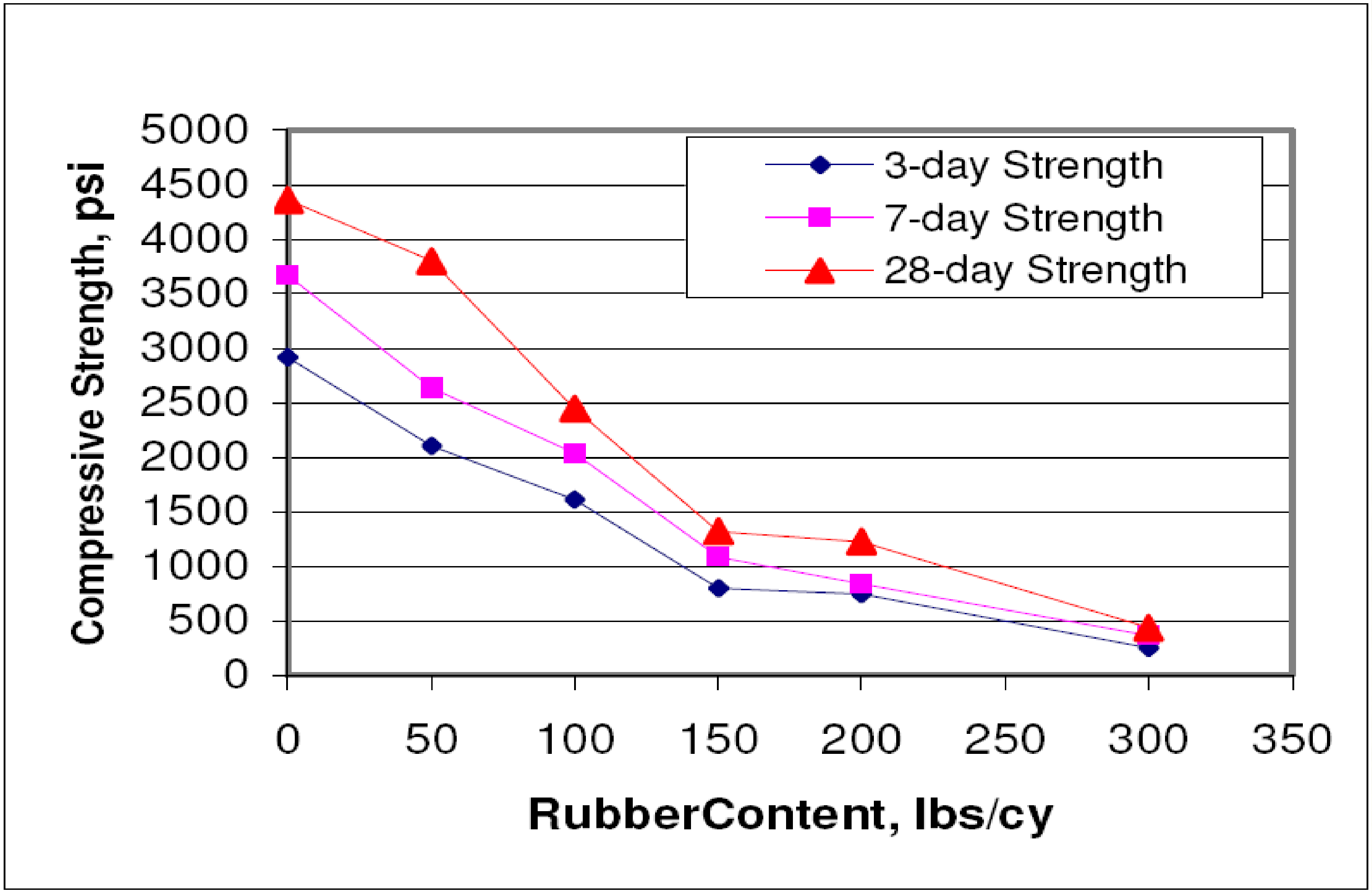
Cross-sectional View of Concrete Samples

(Kaloush et. al. 2004)

Microscopic View of Crumb Rubber Distribution in 400 lbs CR/ Cyd. Mix (Kaloush et. al. 2004)

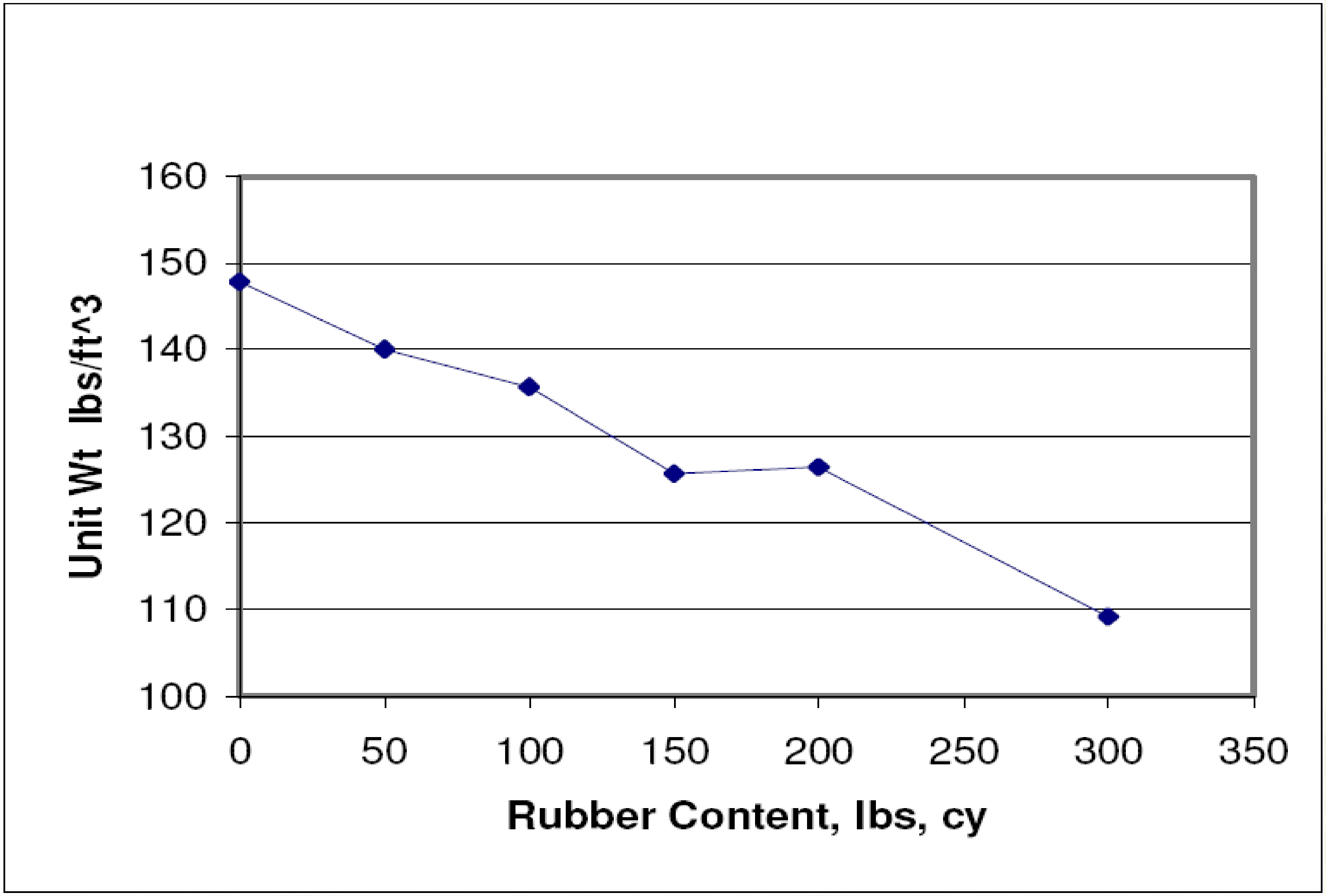
Effect of Rubber Content on Compressive Strength

(Kaloush et. al. 2004)



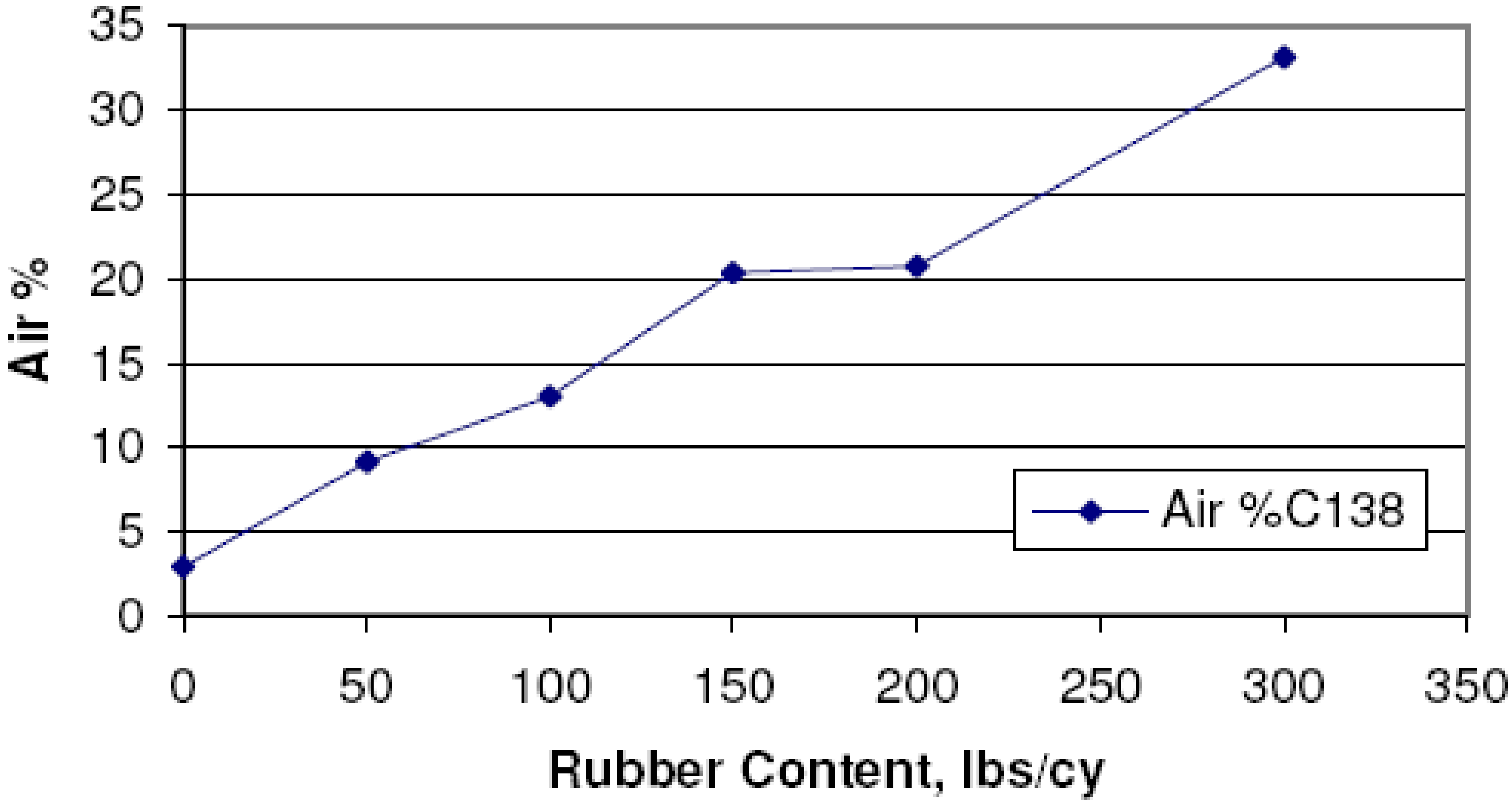
Effect of Rubber Content on Concrete Unit Weight

(Kaloush et. al. 2004)



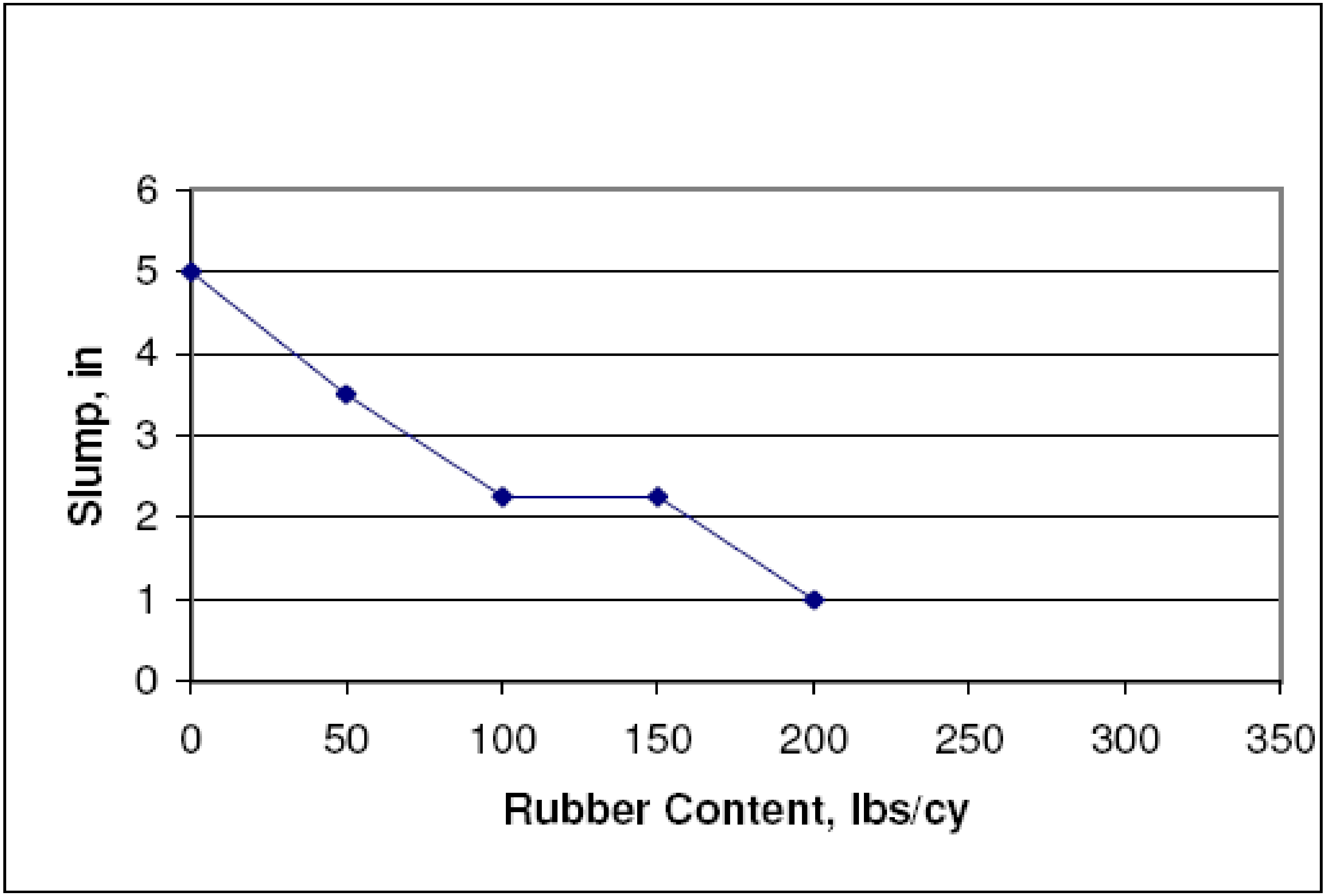
Effect of Rubber Content on Concrete Air Content

(Kaloush et. al. 2004)



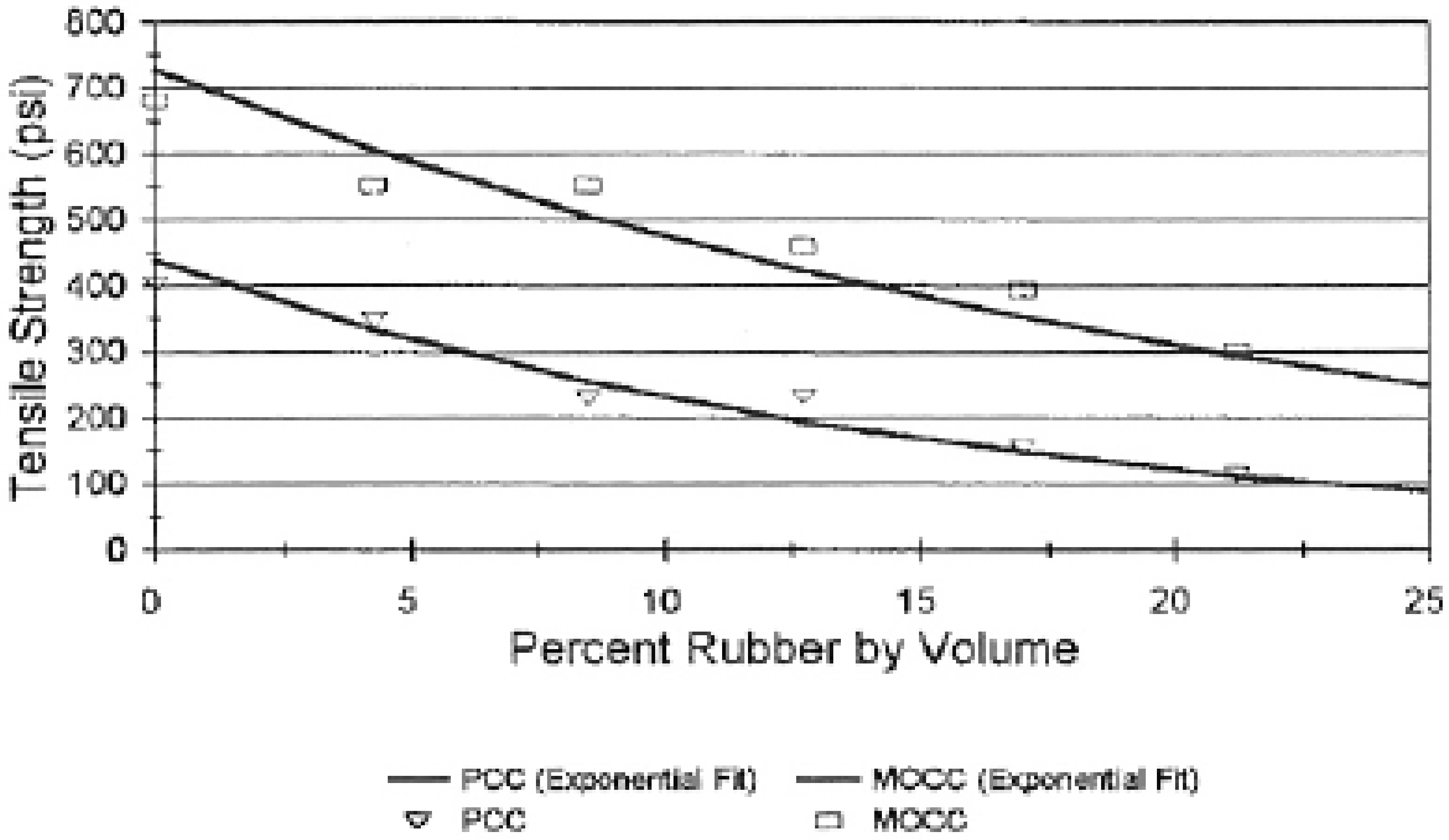
Effect of Rubber Content on Concrete Slump

(Kaloush et. al. 2004)



Split Cylinder Strength vs. Rubber Content

(Biel et. al. 1994)



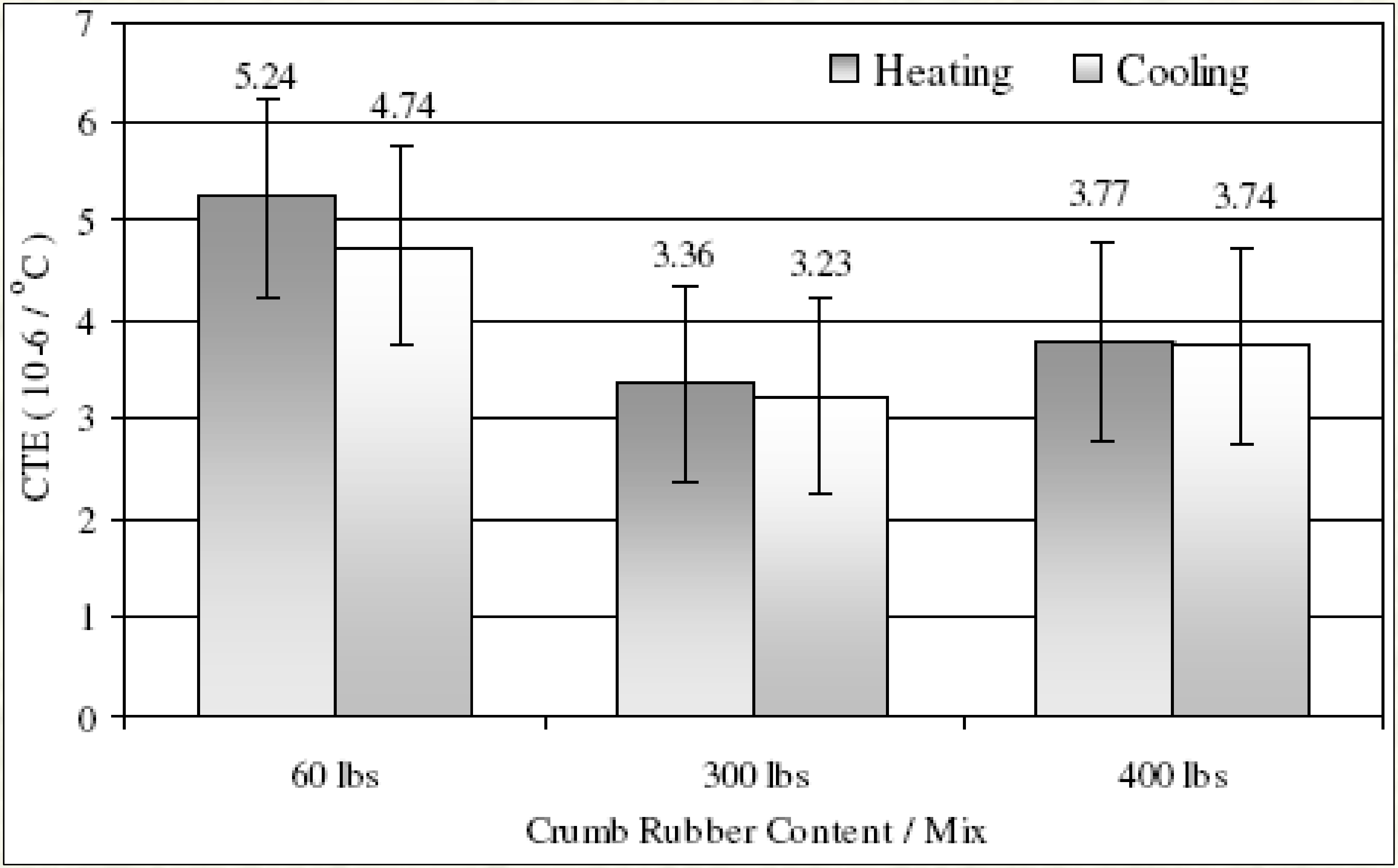
A Tensile Strength Failure of Ordinary Concrete (Kaloush et.al. 2004)

Tensile Strength Failures Crumb Rubber Concrete

(Kaloush et.al. 2004)

Coefficient of Thermal Expansion - CRC

(Kaloush et.al. 2004)



Summary

- A fair amount of research has been done in using waste tire particles in Portland cement concrete
- Concrete compressive strength and stiffness decrease dramatically with increasing rubber content
- However, tensile strain, ductility, and toughness have been shown to increase with small amounts of rubber particles

Potential Applications

- Light duty paving (sidewalks, etc.)
- Vibration mitigation
- Energy absorption (earthquake)
- Increase freeze/thaw durability
- Others?

THANK YOU

Questions?

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