

Moisture Damage Inhibitors Hydrated Lime

Evaluating the Impact of
Hydrated Lime as a Filler

Literature suggests that hydrated lime

- Serves as an active filler in some bitumens and reduces high temperature deformation
- Has a lesser impact as a filler at low temperatures – ability to relax retained
- Improves fracture toughness at low temperatures
- Improves the adhesive bond between aggregate and bitumen

Mechanisms of Bond Improvement

■ Dirty aggregates

- Pozzolanic reaction with active minerals

■ Siliceous aggregates

- H-bond between water and aggregate SiOH group preferred over SiOH and COOH
- $\text{Ca}(\text{OH})_2$ provides Ca^{++} to react with COOH to provide bond with stronger nitrogen groups
- Ca^{++} migrates to aggregate surface to replace H^+ , Na^+ , and K^+ (and other cations)

Mechanisms of Bond Improvement, cont'd

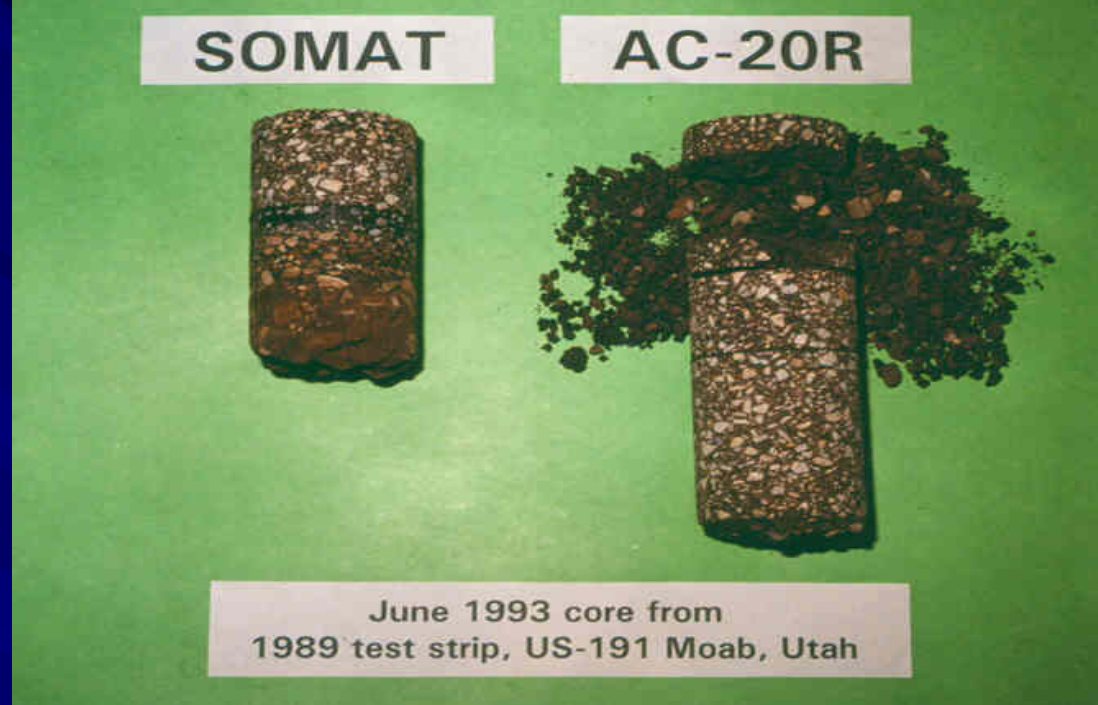
■ In bitumen

- Conversion of RCOOH to Ca^{++} based salts before mixing with aggregate could prevent adsorption of water sensitive free acids to begin with
- Active effect in bitumen (AAD) – Petersen and Little (2004)
 - Strong interaction between HL (strong base) and carboxylic acids in AAD
 - 60% of carboxylic acids and over 90% of 2-quinolones in AAD are in amphoteric
 - Polyfunctional amphoteric can link or bind associated molecular agglomerations to form larger associations

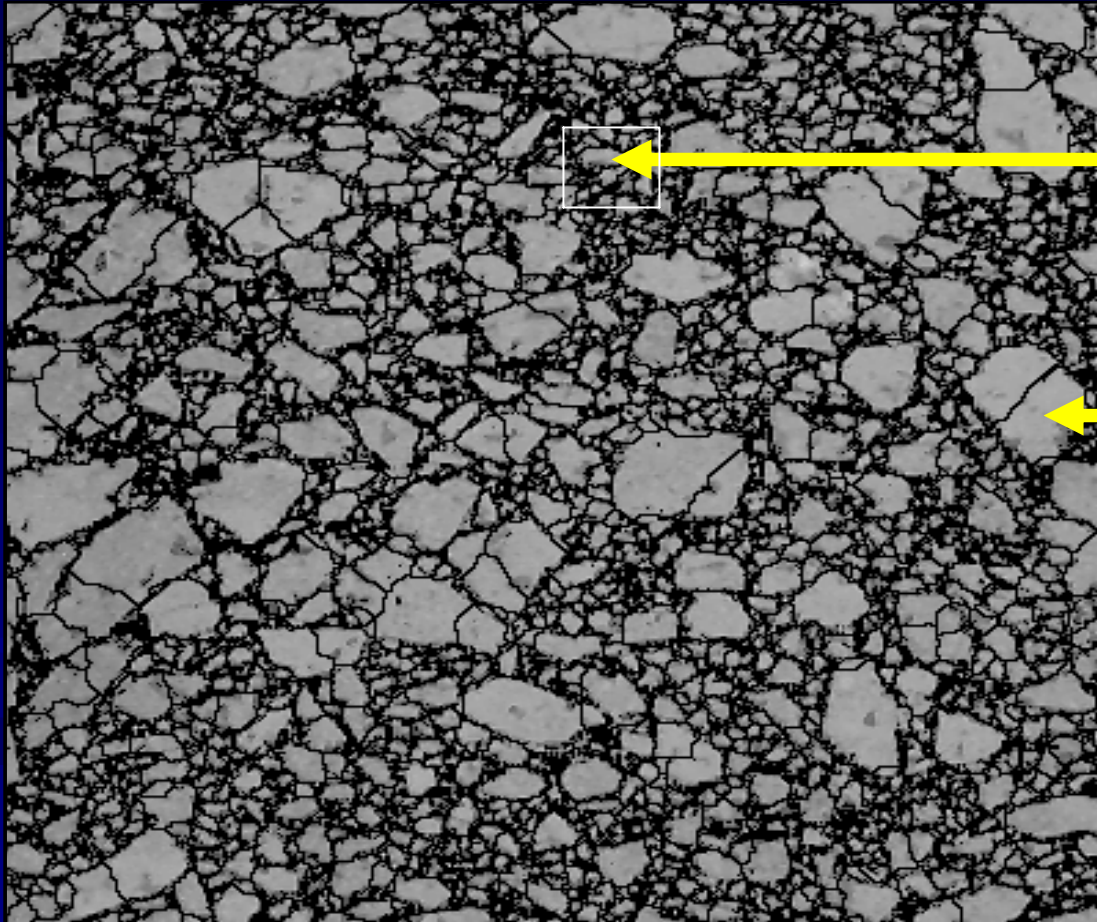
Moisture Damage – Loss of strength and durability due to effects of Moisture

(1) Loss of bond

(2) Weakening of
mastic and/or
mastic and fine
aggregate



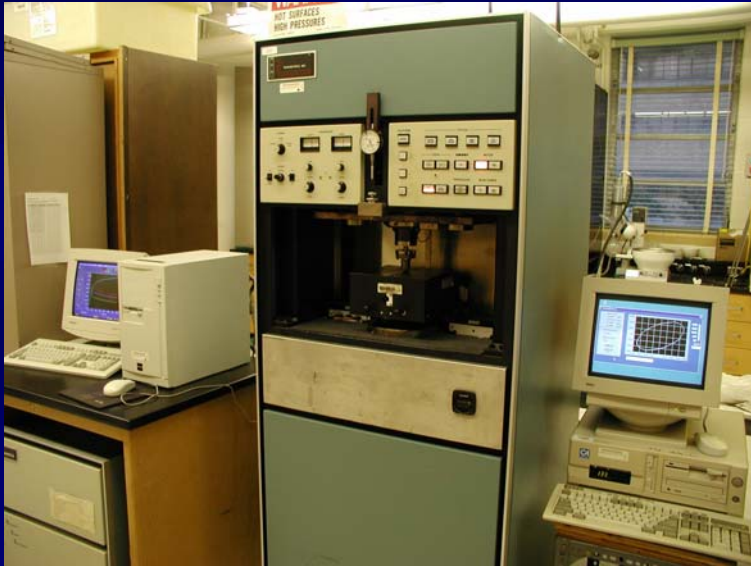
The Mixture



Fine aggregate
and mastic

Coarse aggregate

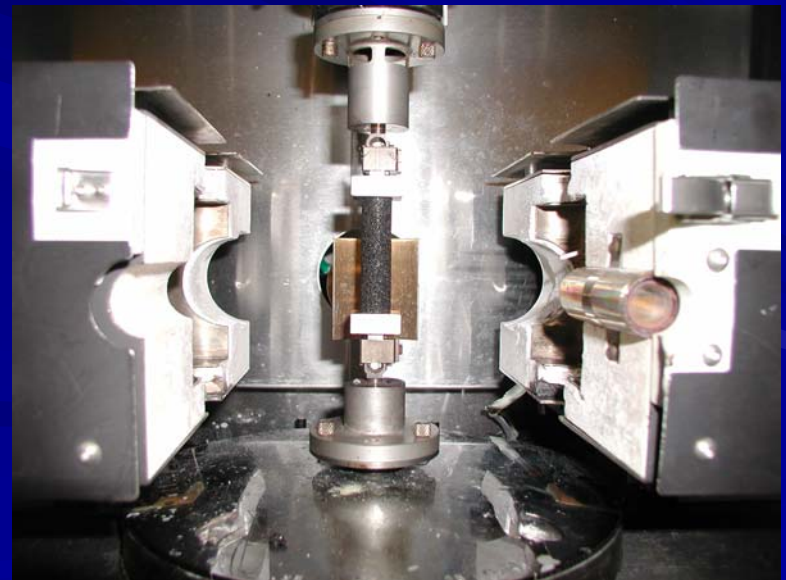
The DMA Experiment



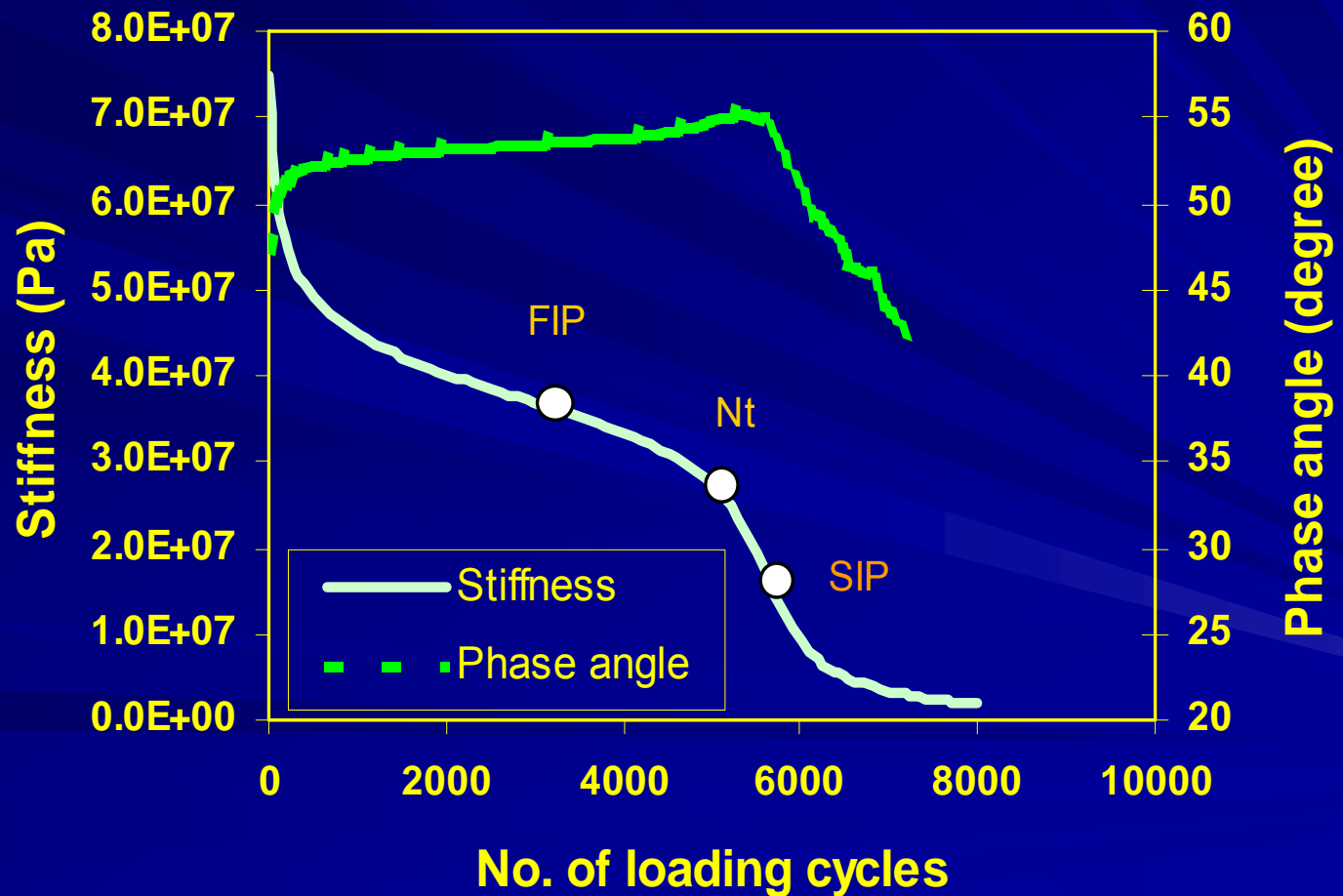
Rheometer and data acquisition

Sample set up in temperature control unit

50-mm high; 12-mm in diameter



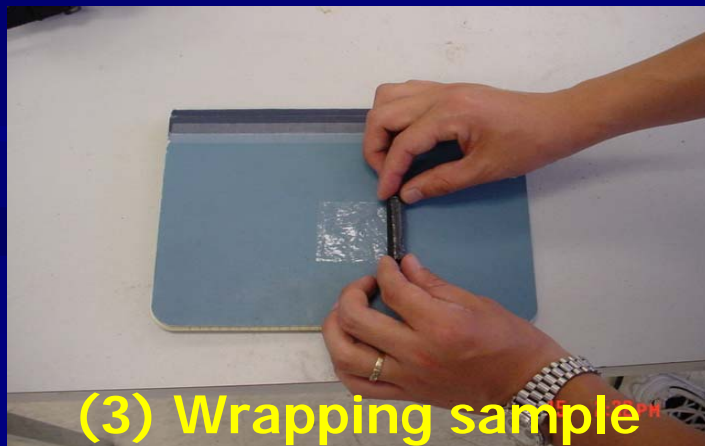
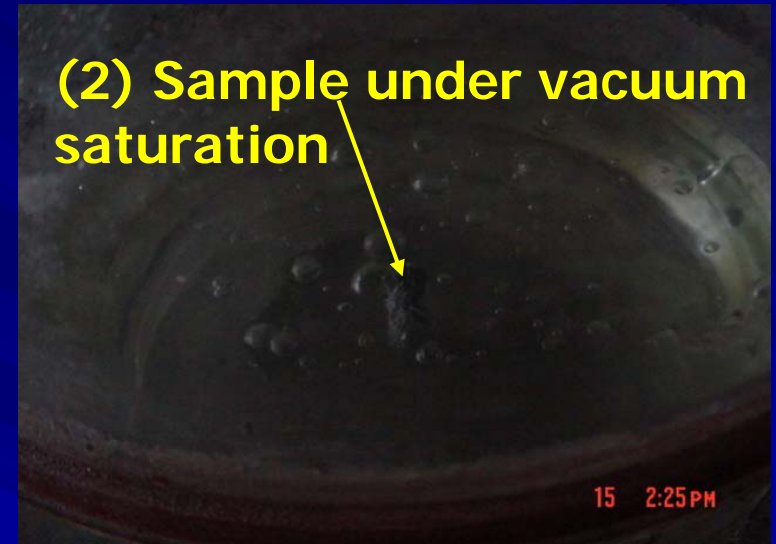
Shear Modulus (Stiffness) and Phase Angle versus Number of Loading Cycles in Fatigue Testing



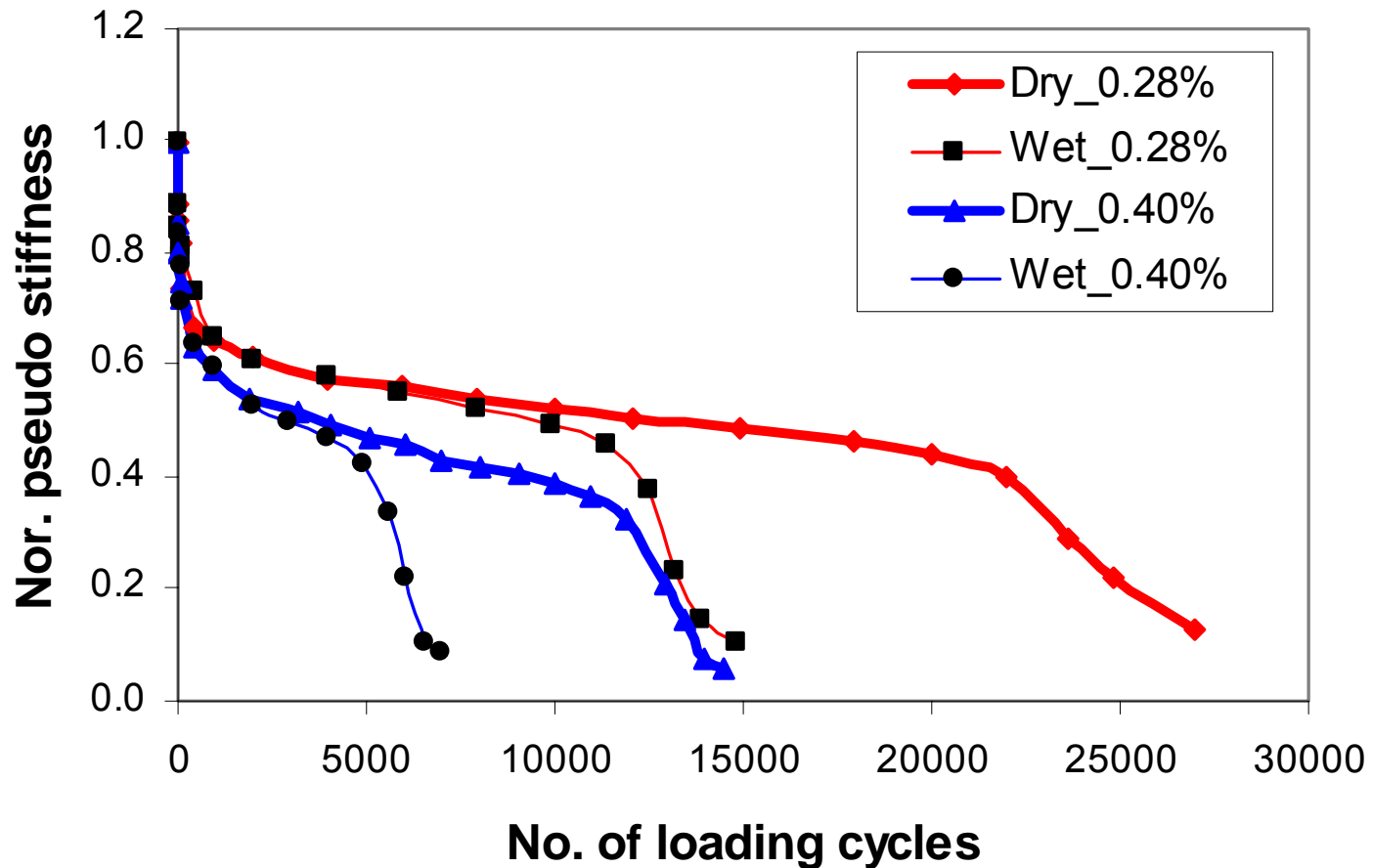
Parameters Used to Monitor DMA Test Results

- Change in shear stiffness (normalized)
 - We want to see a slow rate of change in shear modulus
- Dissipated pseudo strain energy v. load cycle
 - We want these values to be low
- Cumulative dissipated pseudo strain energy (CDPSE)
 - We want this value to be high
- Damage parameter by CT imaging – ξ
 - We want this value to be low and to validate G v. N, DPSE v. N, and CDPSE

Fabrication of DMA Sample for Moisture Sensitivity Testing



Damage in DMA: Effect of Moisture



Impact of HL on Cycles to Failure (dry and wet)

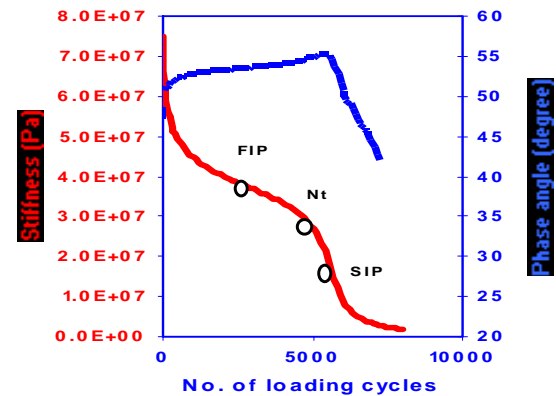
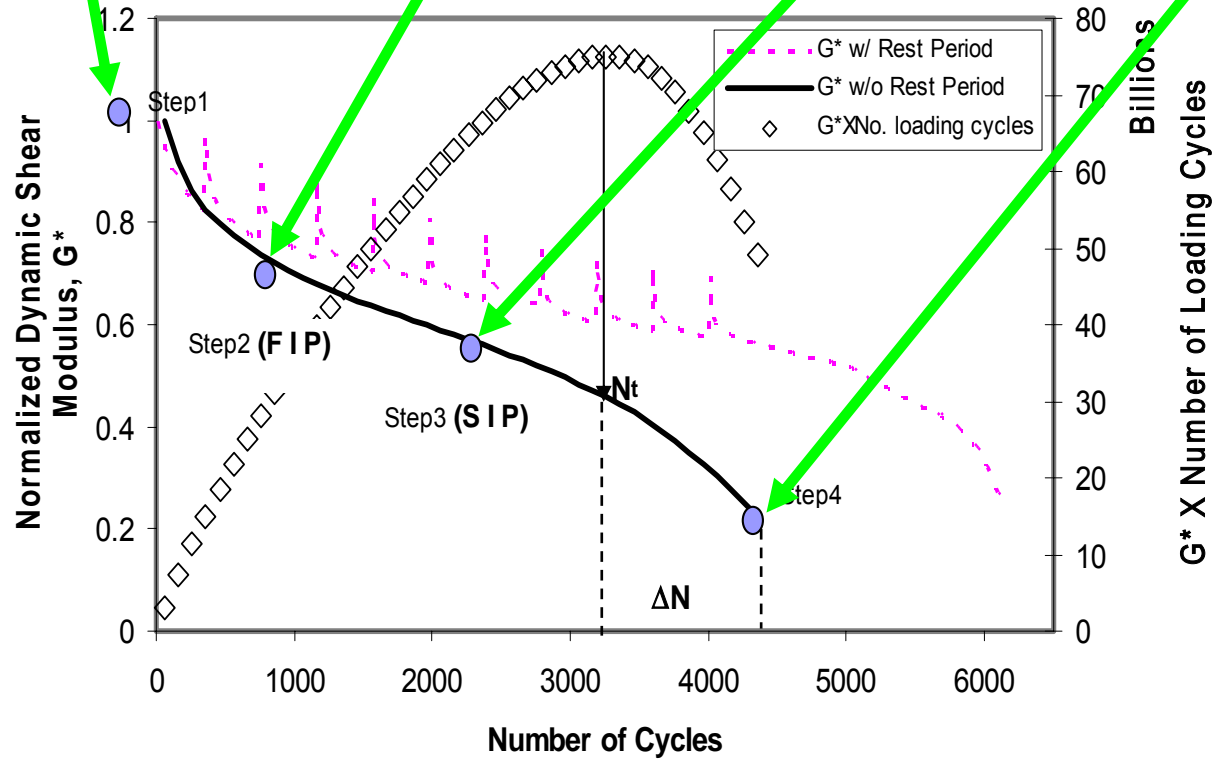
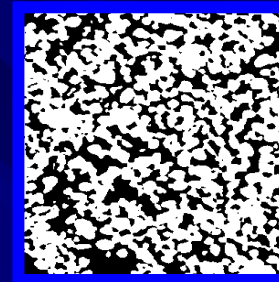
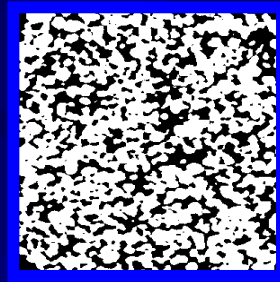
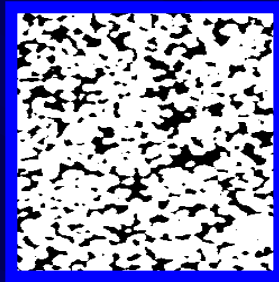
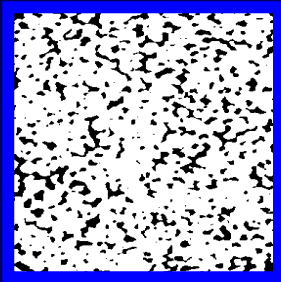
Asphalt	Mineral Filler	N_f (dry)	N_f (wet)
AAM-1	Limestone	4,000	2,100
AAM-1	Hydrated Lime	8,200	6,200
AAD-1	Limestone	5,200	2,500
AAD-1	Hydrated Lime	10,000	8,500

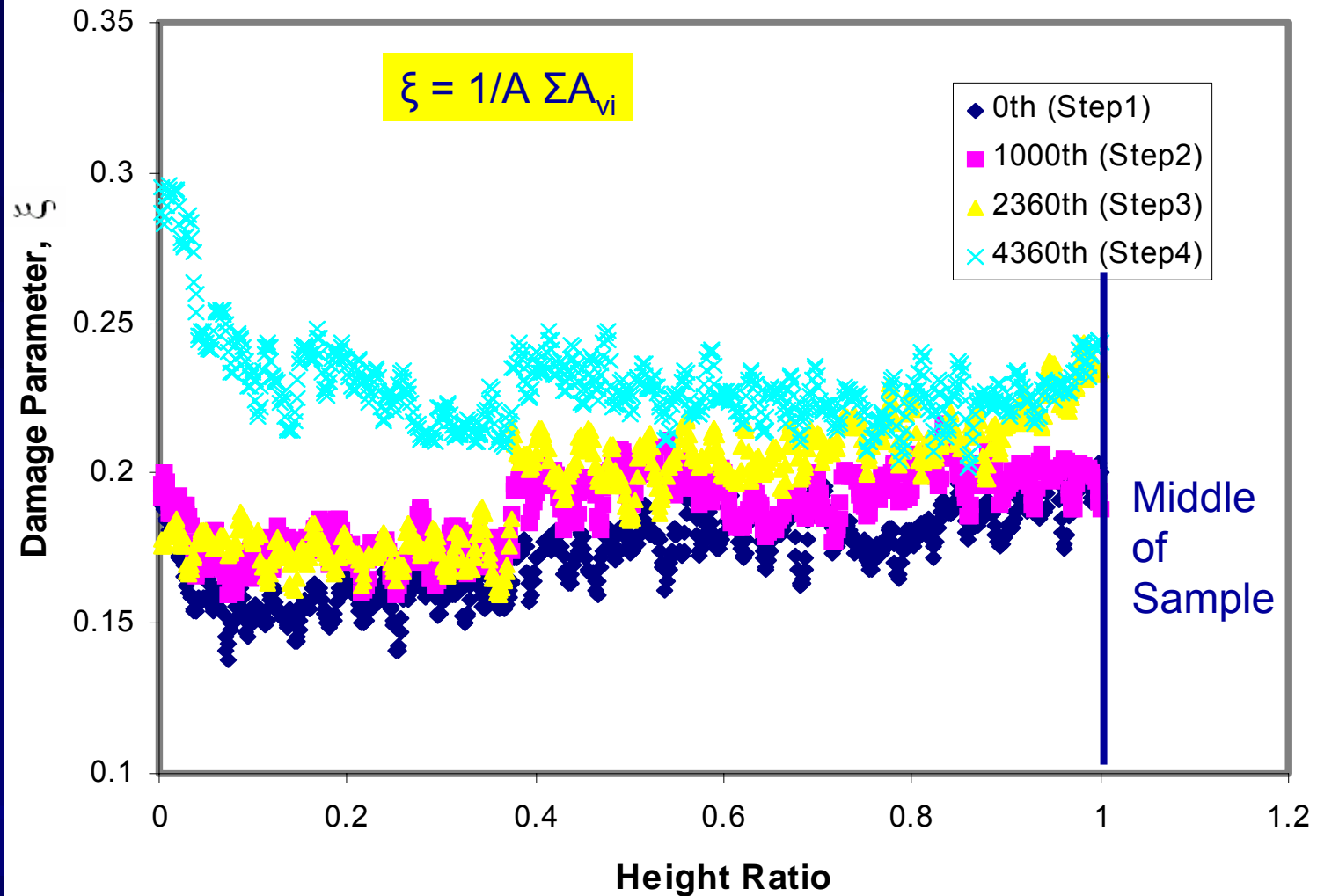
Step 1

Step 2

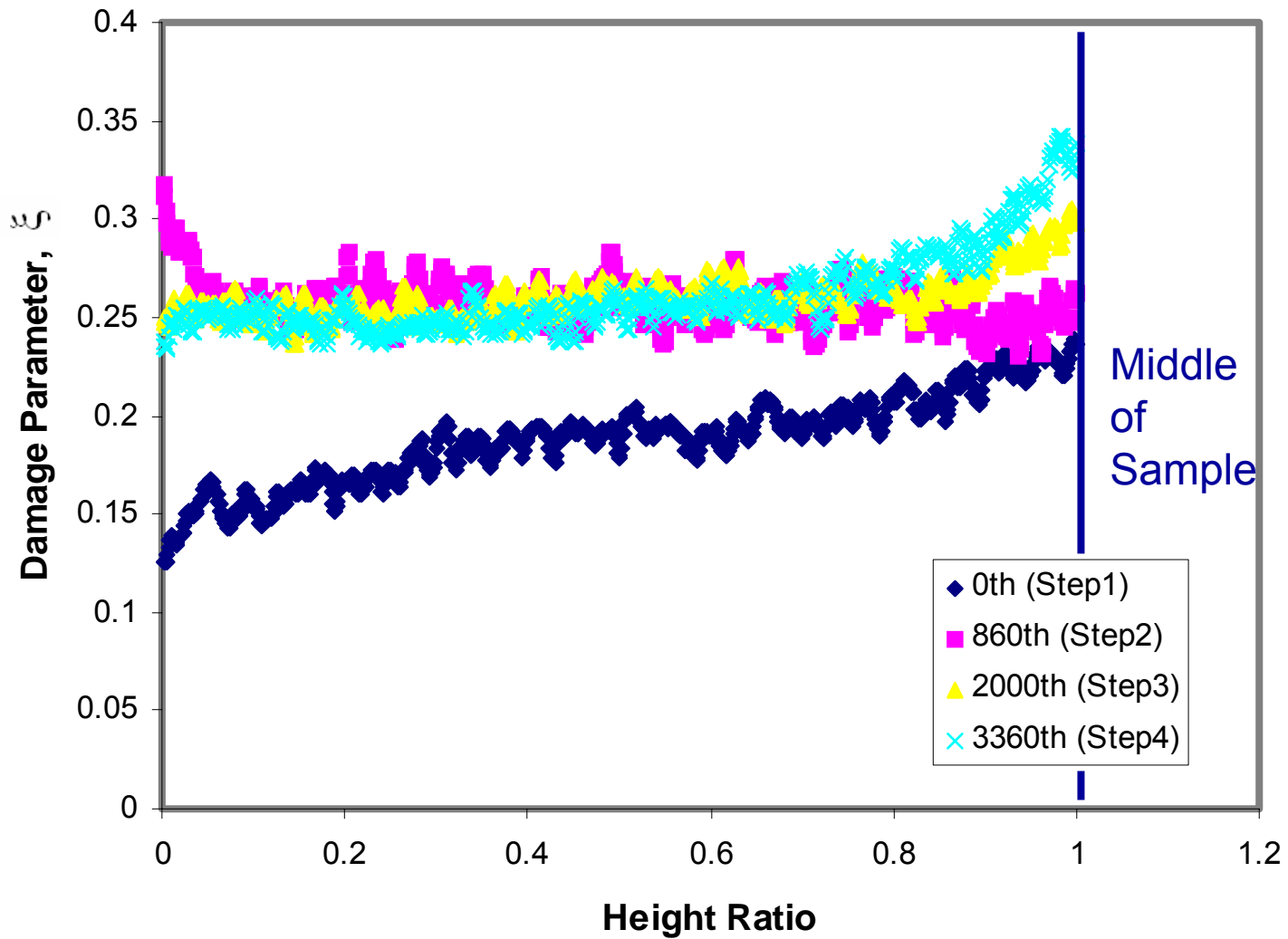
Step 3

Step 4





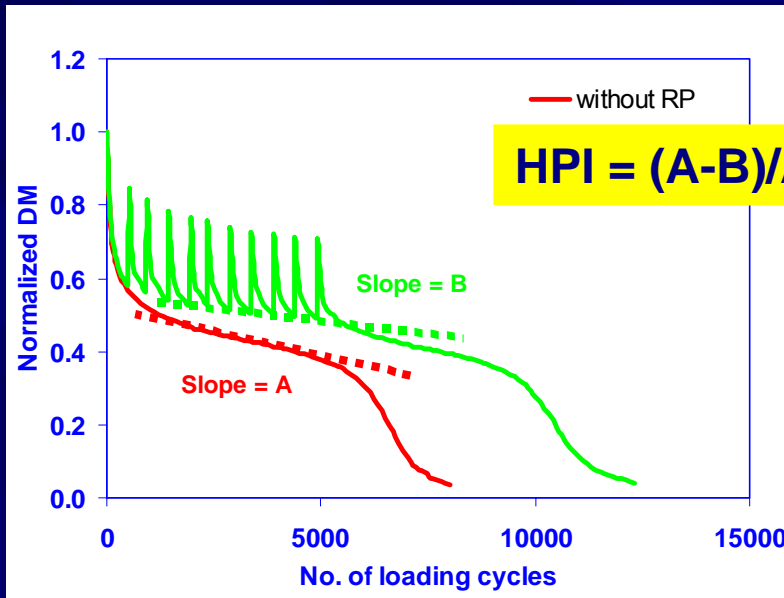
Dry samples (no rest periods) – Little change from step 1 to step 2; significant change from step 3 to step 4



Wet samples (no rest periods) – Damage occurs early

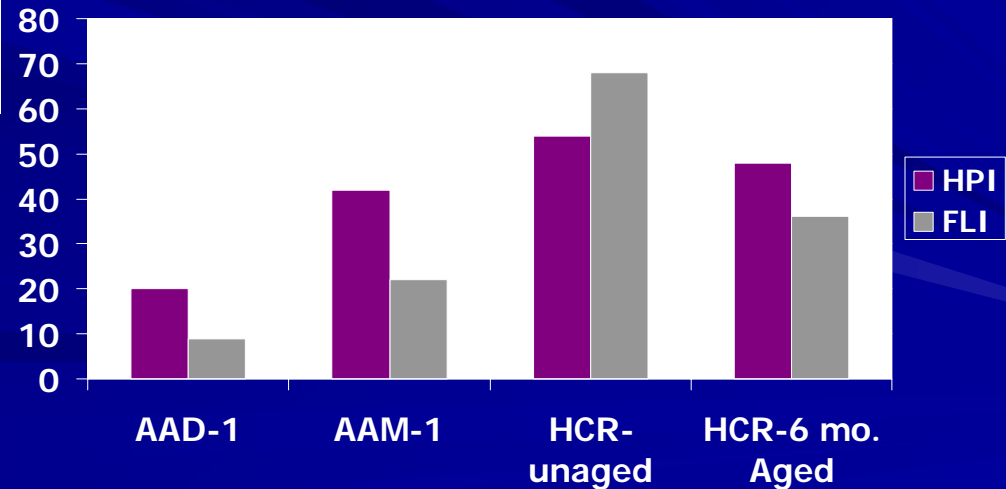
Healing Effect - HPI

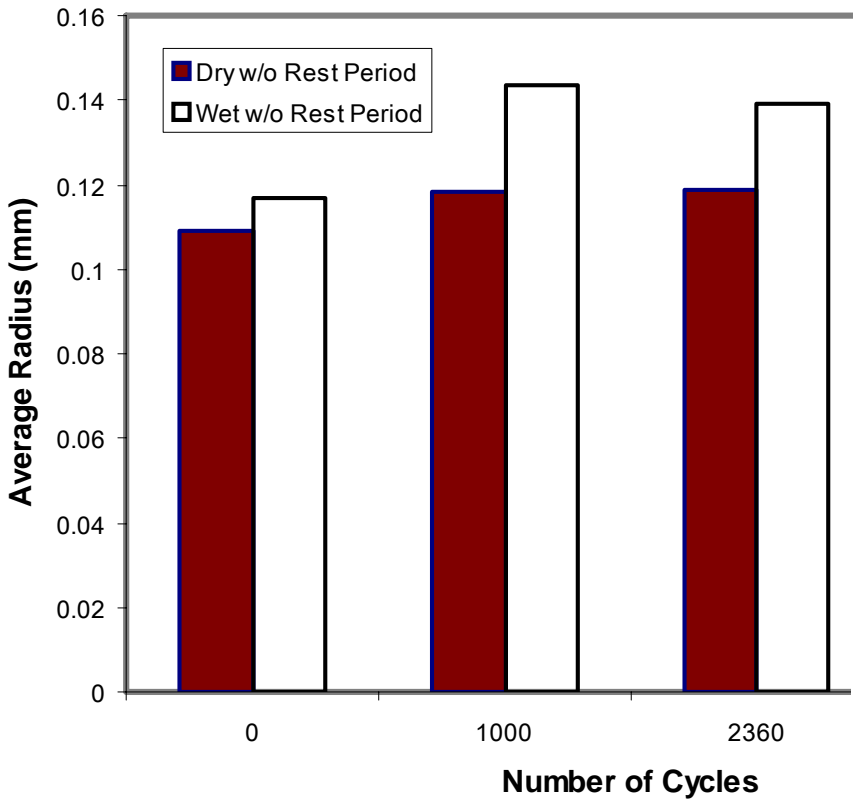
Research for FHWA (Subcontract to WRI)



$$HPI = (A-B)/A$$

Average Value, %



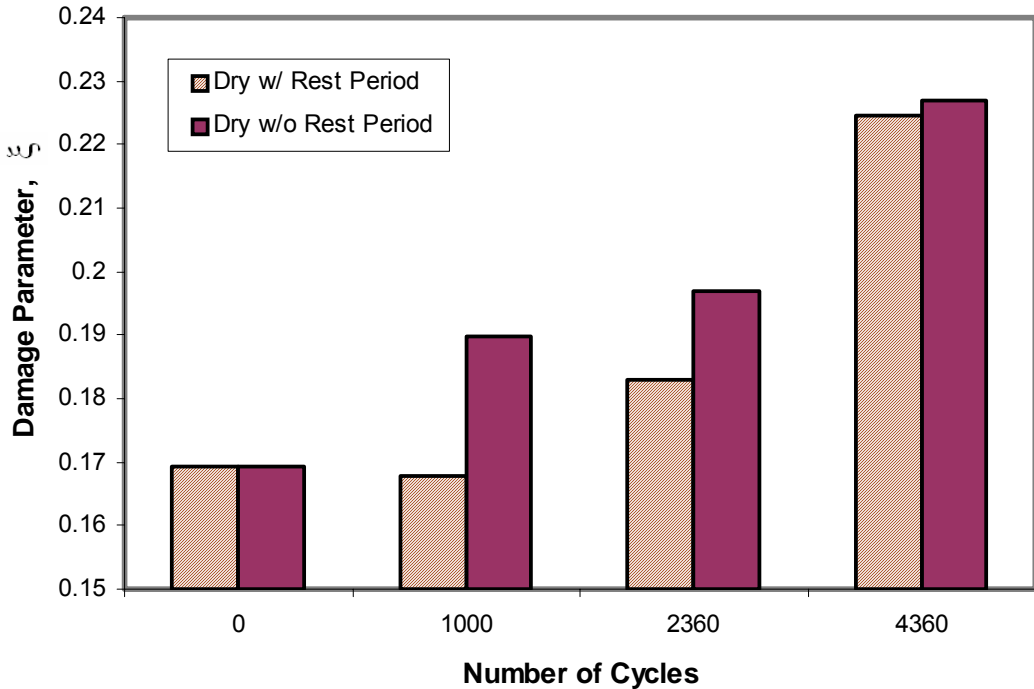


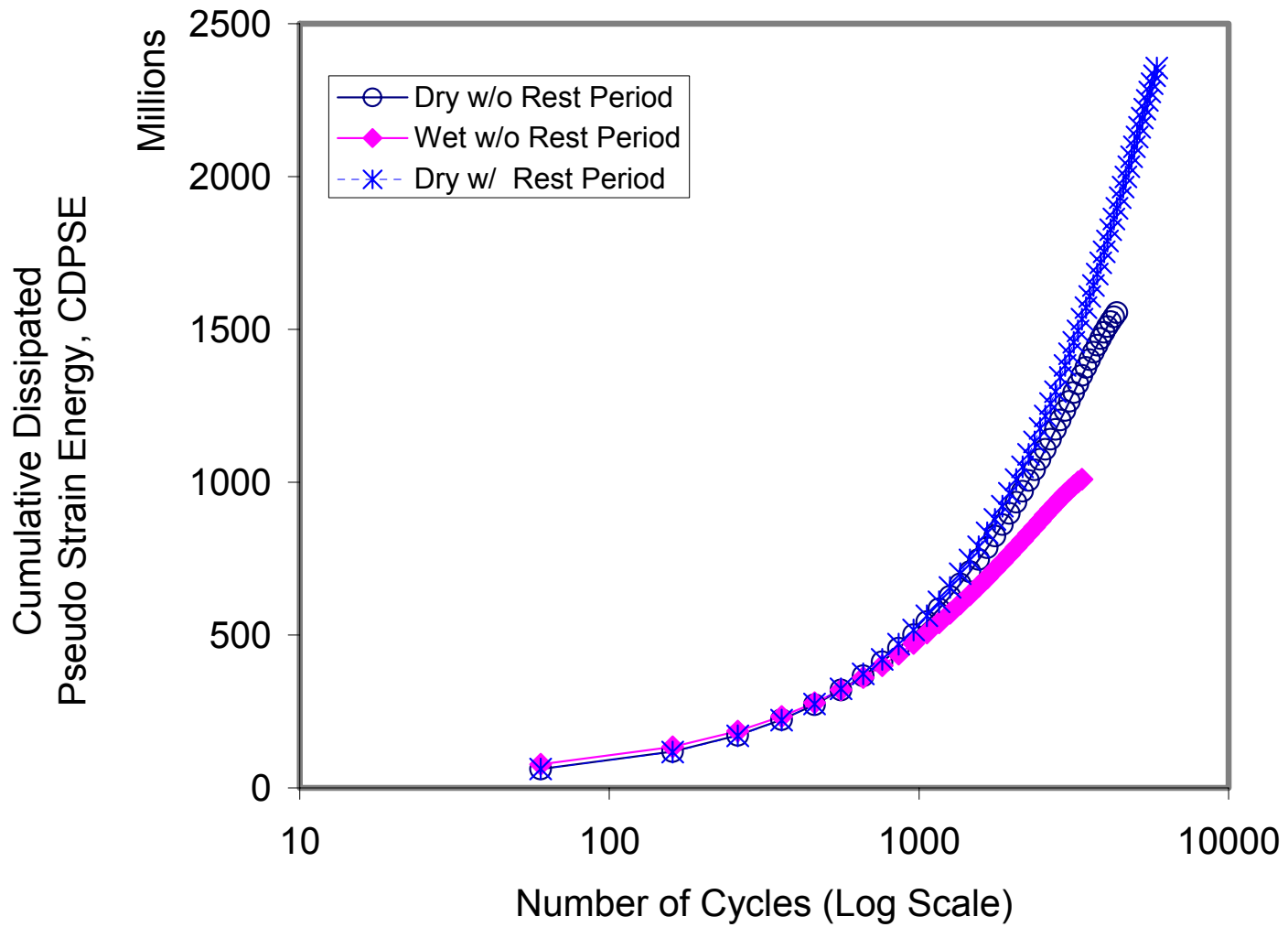
Average void radii for dry and Wet samples

Higher initial void size consistent With measured saturation of Over 100 %

Impact of rest periods on ξ

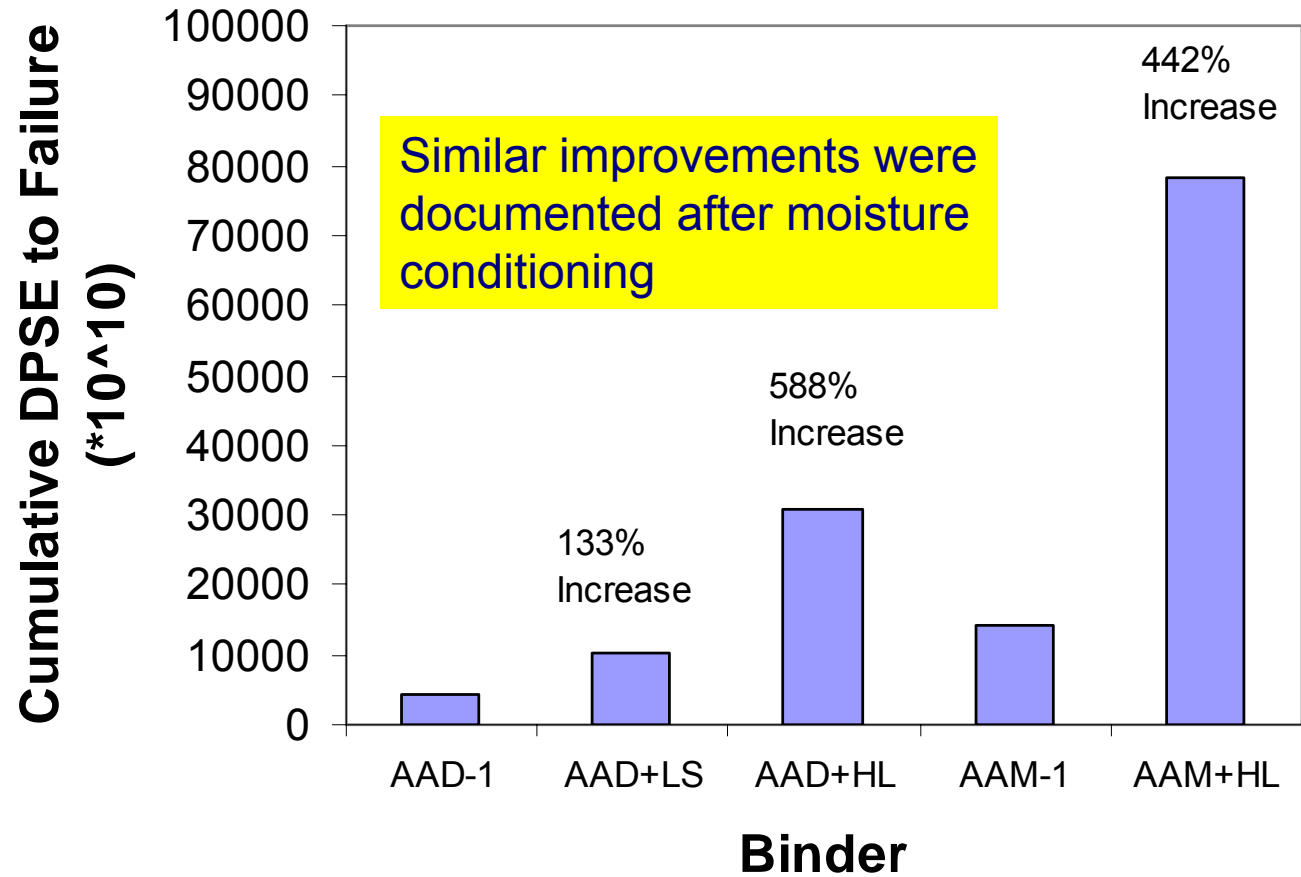
Note strong impact early on



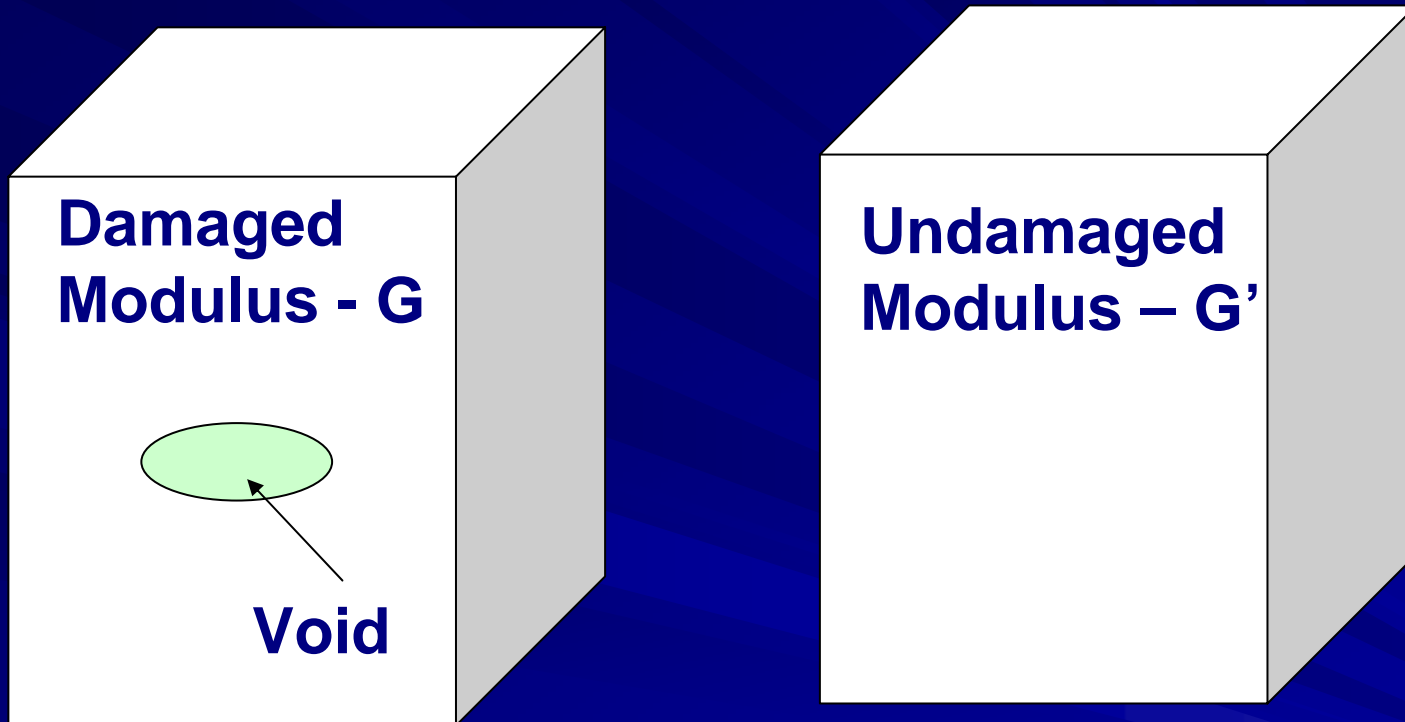


Comparison of CDPSE

(@ Same Strain Level)



Energy remains the same in both systems



$G'/G = f$ [thickness of mastic, average size (radius of cracks), cross-sectional area of sample, number of cracks, applied shear stress, adhesive bond strength, cohesive bond strength]

Cohesive Damage

$$\frac{G'}{G} = \left[1 - 2\pi^2 \left(\frac{m}{A} \right) \frac{\bar{r}^{-3}}{t} \left(1 - \frac{G \Delta G_f^c}{\pi \tau^2 \bar{r}} \right) \right]$$
$$= \left[1 - 2\pi \xi \frac{\bar{r}}{t} \left(1 - \frac{G \Delta G_f^c}{\pi \tau^2 \bar{r}} \right) \right]$$

Terms A, m, t, r, and ξ are derived from CT Imaging

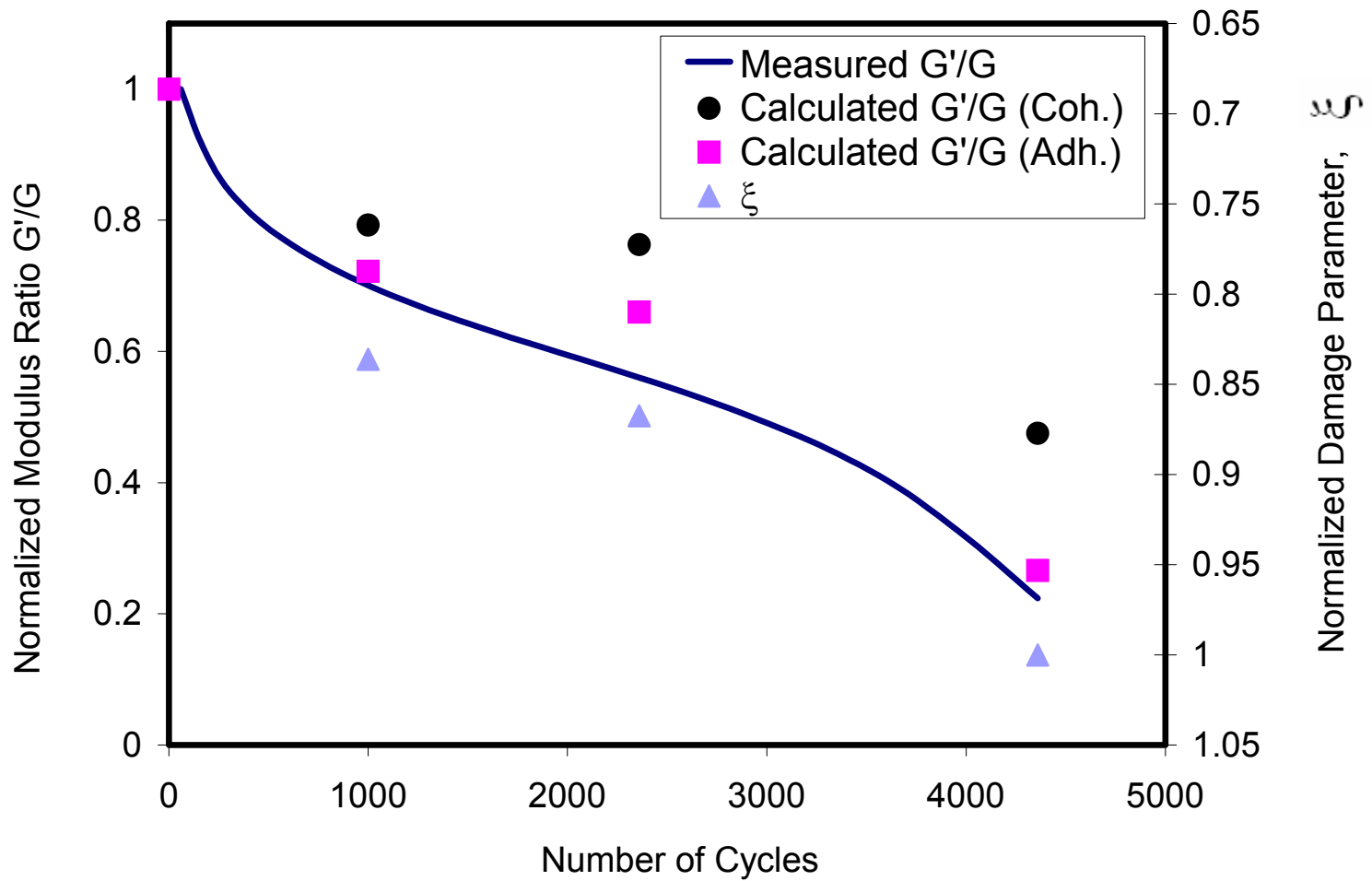
ΔG^c is calculated for surface energy measurements

Tau and G are determined from DMA

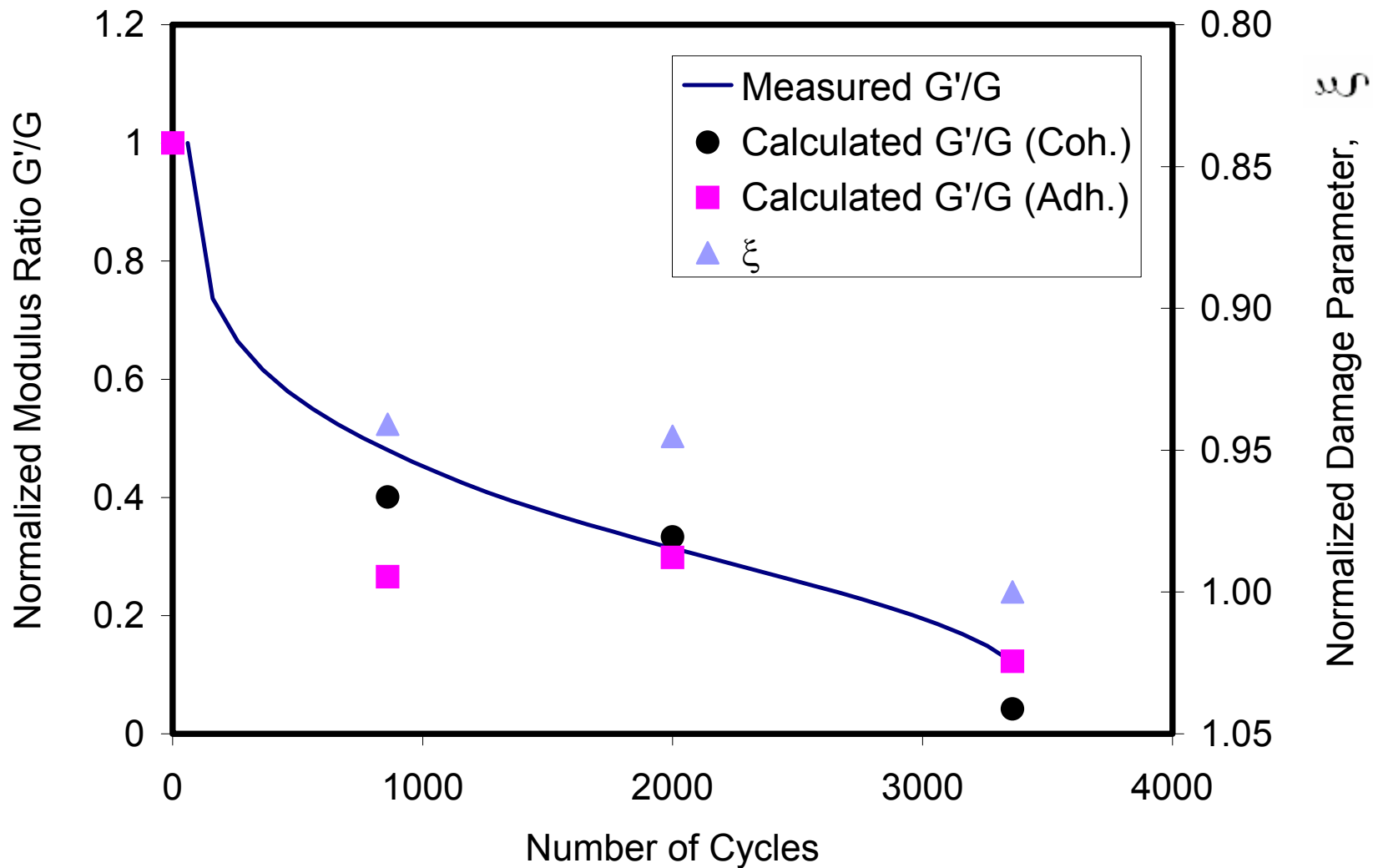
Adhesive Damage

$$\frac{G'}{G} = \left[1 - \pi^2 \left(\frac{m}{A} \right) \frac{\bar{r}^{-3}}{t} \left[\left(1 + \frac{G}{G_s} \right) - \frac{4G_f (\Delta G^a)}{\pi \tau^2 \bar{r}} \right] \right]$$
$$= \left[1 - \pi \xi \frac{\bar{r}}{t} \left[\left(1 + \frac{G}{G_s} \right) - \frac{4G_f (\Delta G^a)}{\pi \tau^2 \bar{r}} \right] \right]$$

Added terms are G_s and ΔG_a



Dry condition



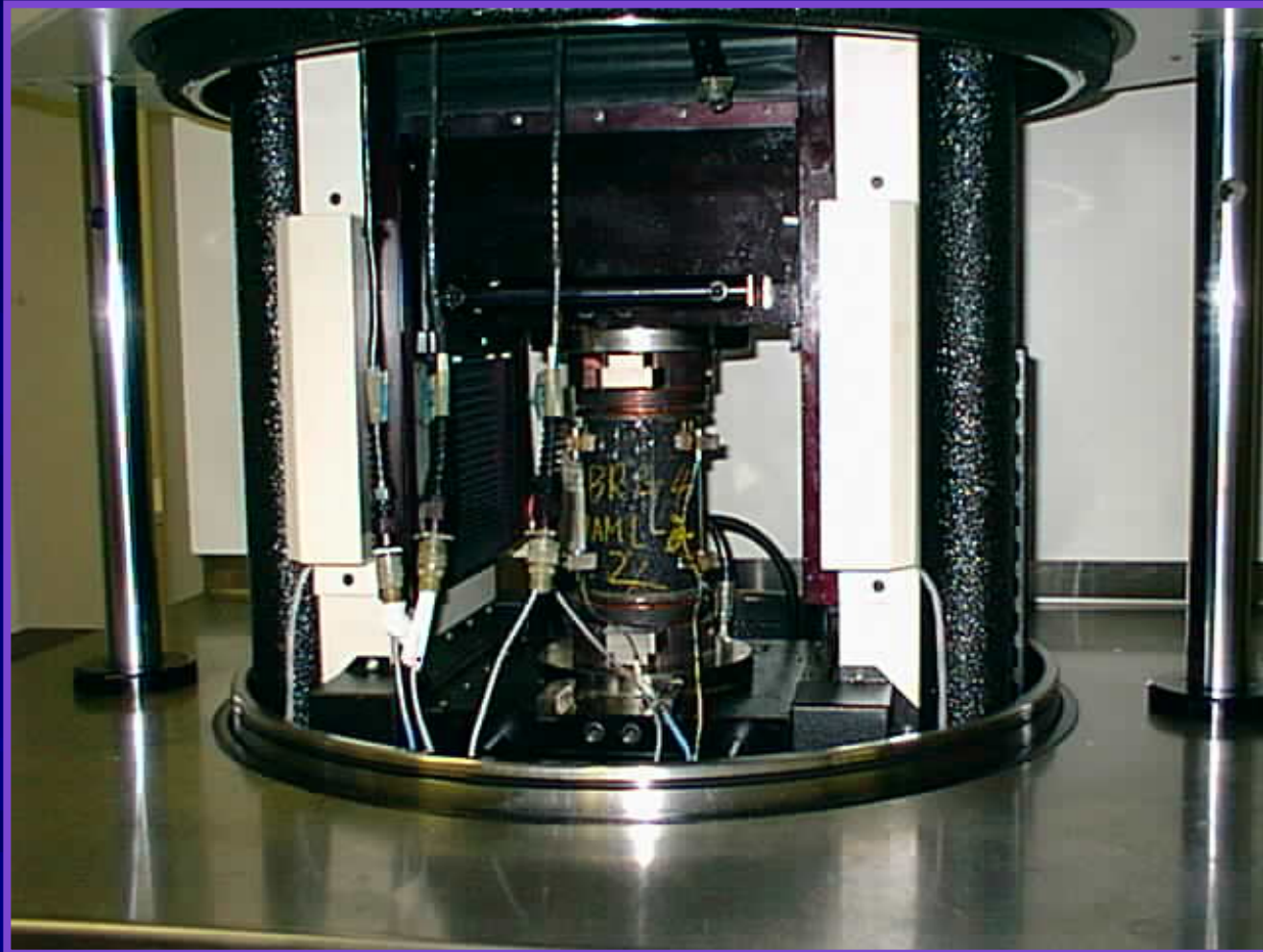
Wet Condition

Comparison with Mixture Tests

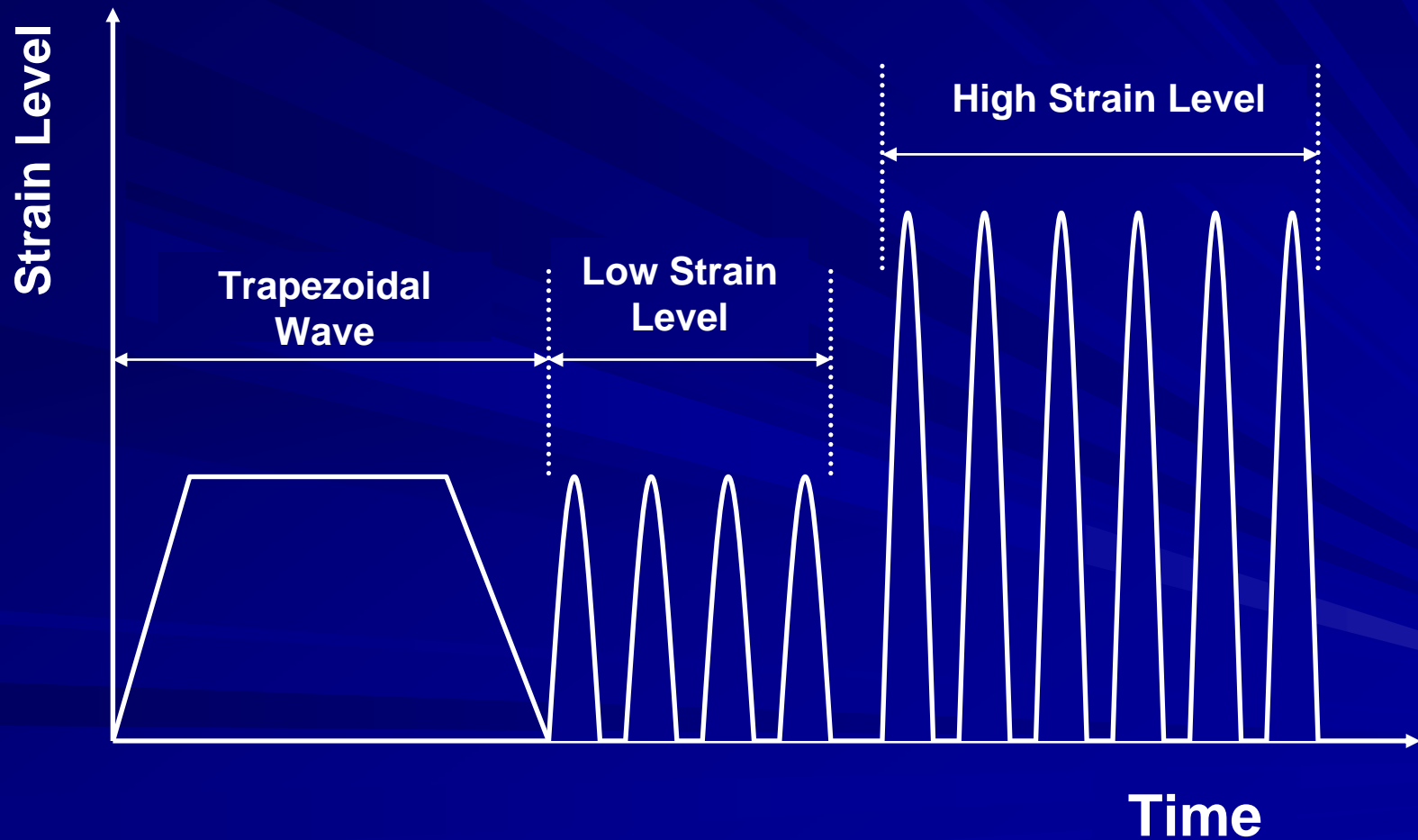
Superpave Shear Tester (SST) – Intermediate Temperature



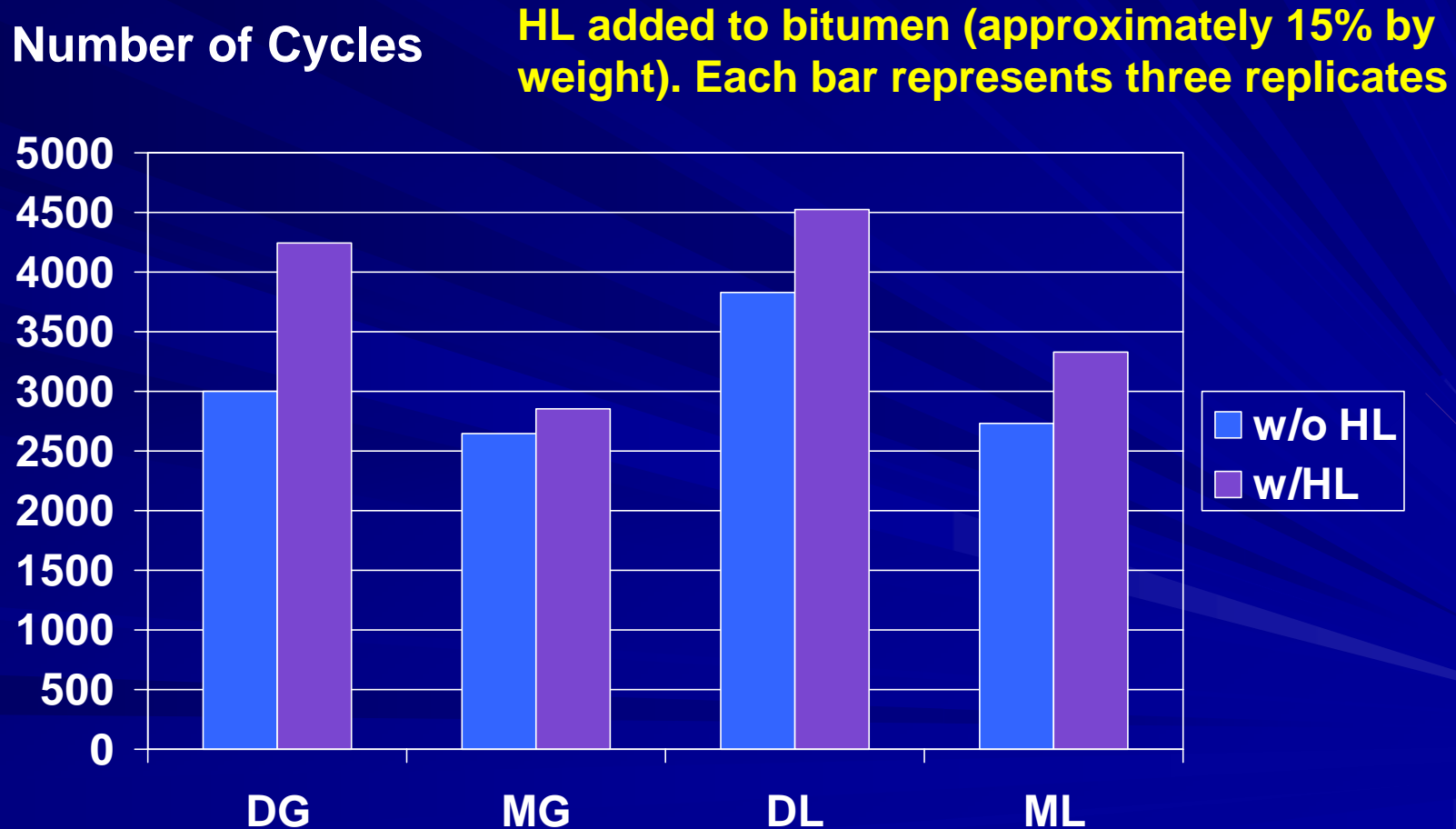
Close-up of Test Setup



Input Strain Waveform



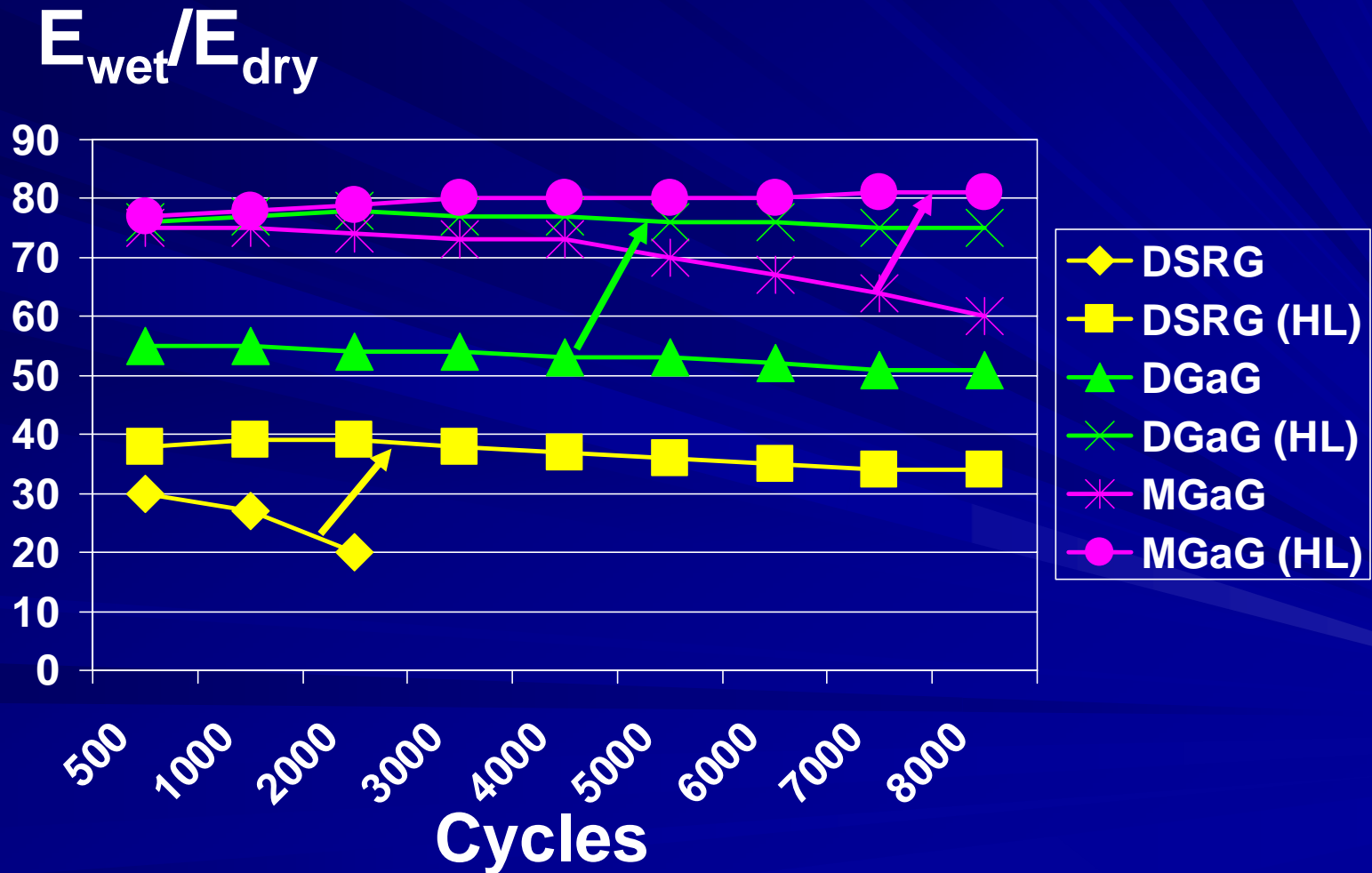
Effect of HL on Cycles to Direct Tensile Fatigue Failure



Repeated Load Permanent Deformation Testing (Dry and Near Saturation)

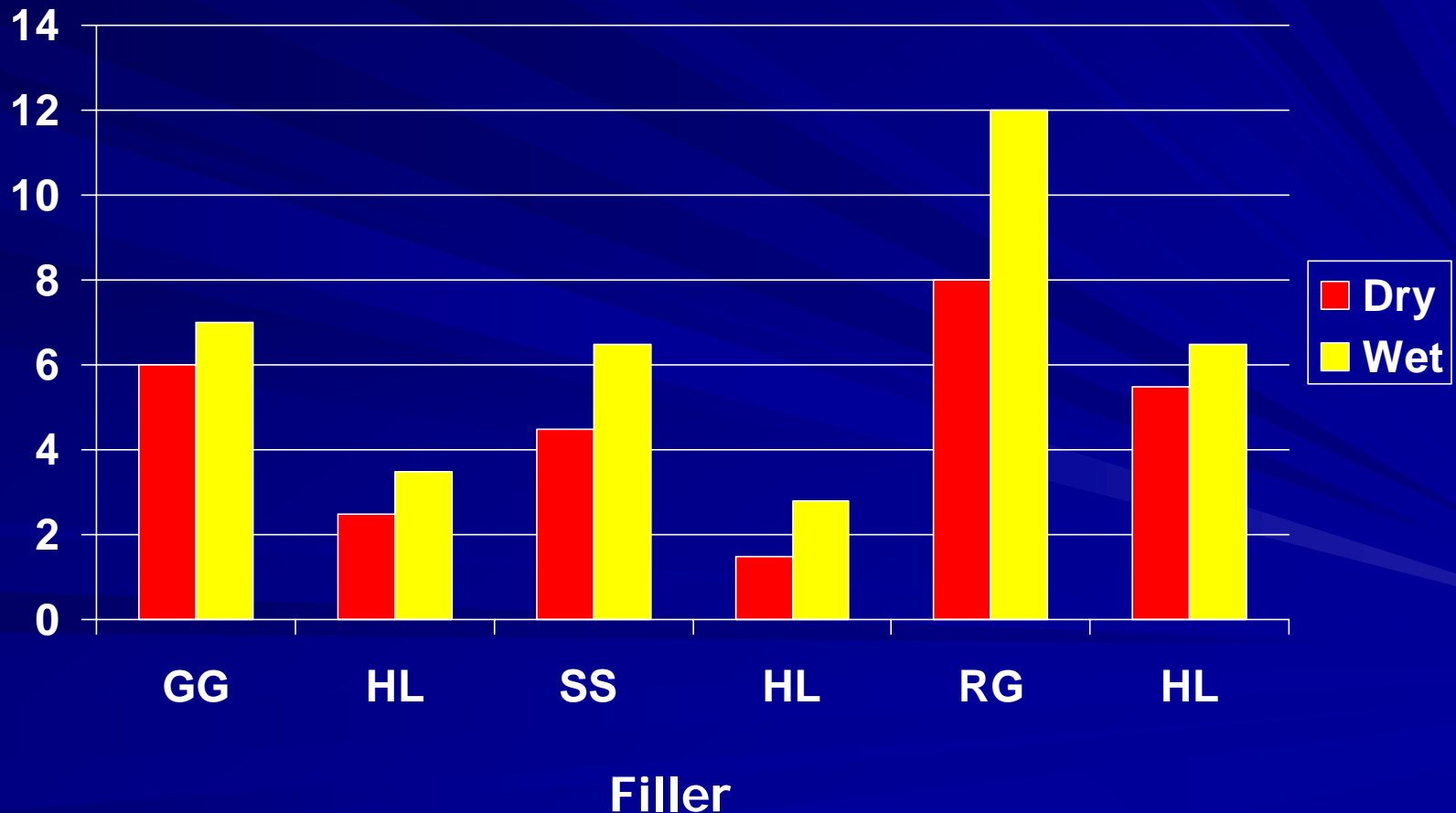


E_{wet}/E_{dry} in Repeated Load Testing (85% Saturation)

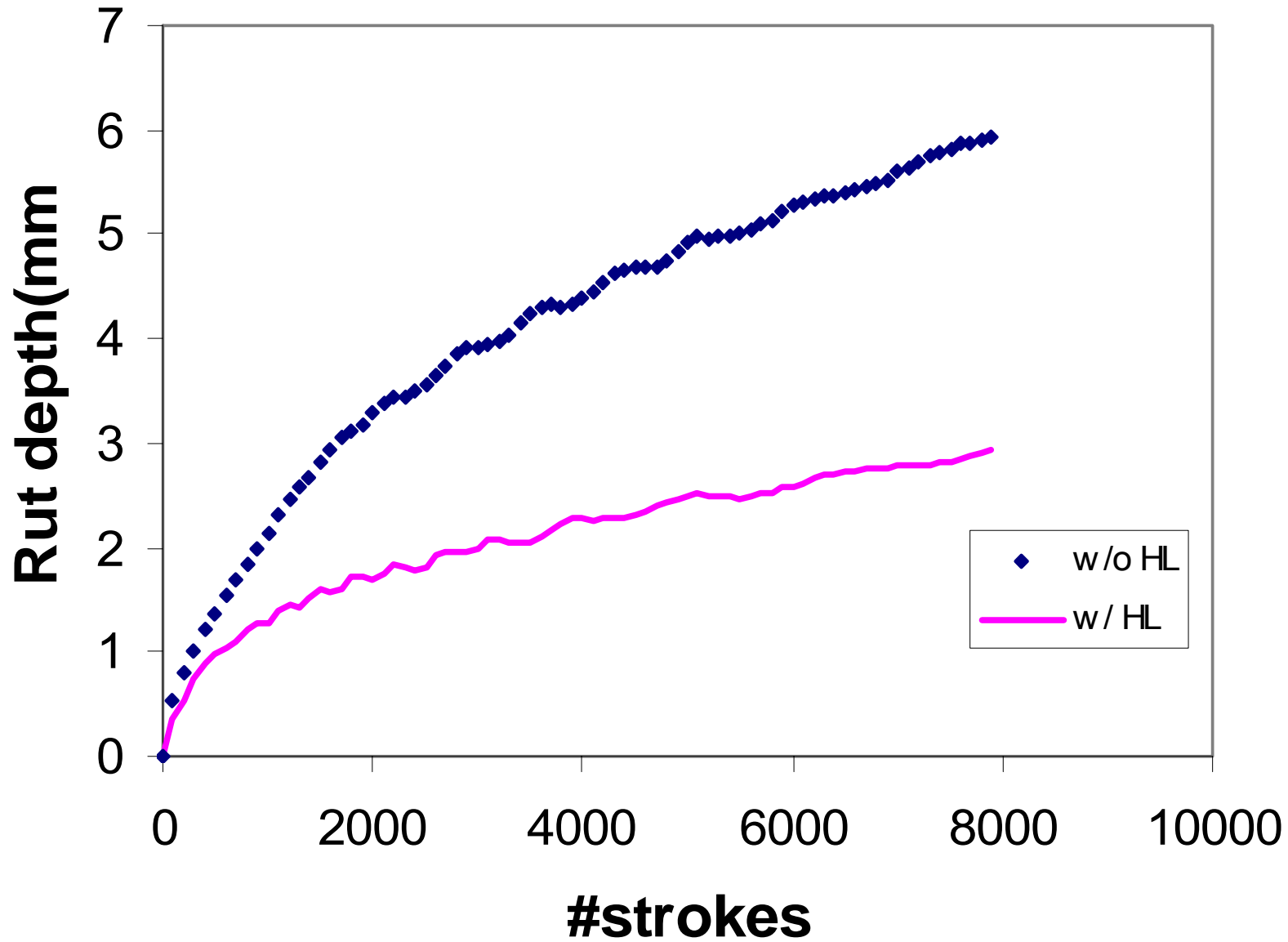


Comparative APA Results (AAD + Aggregate)

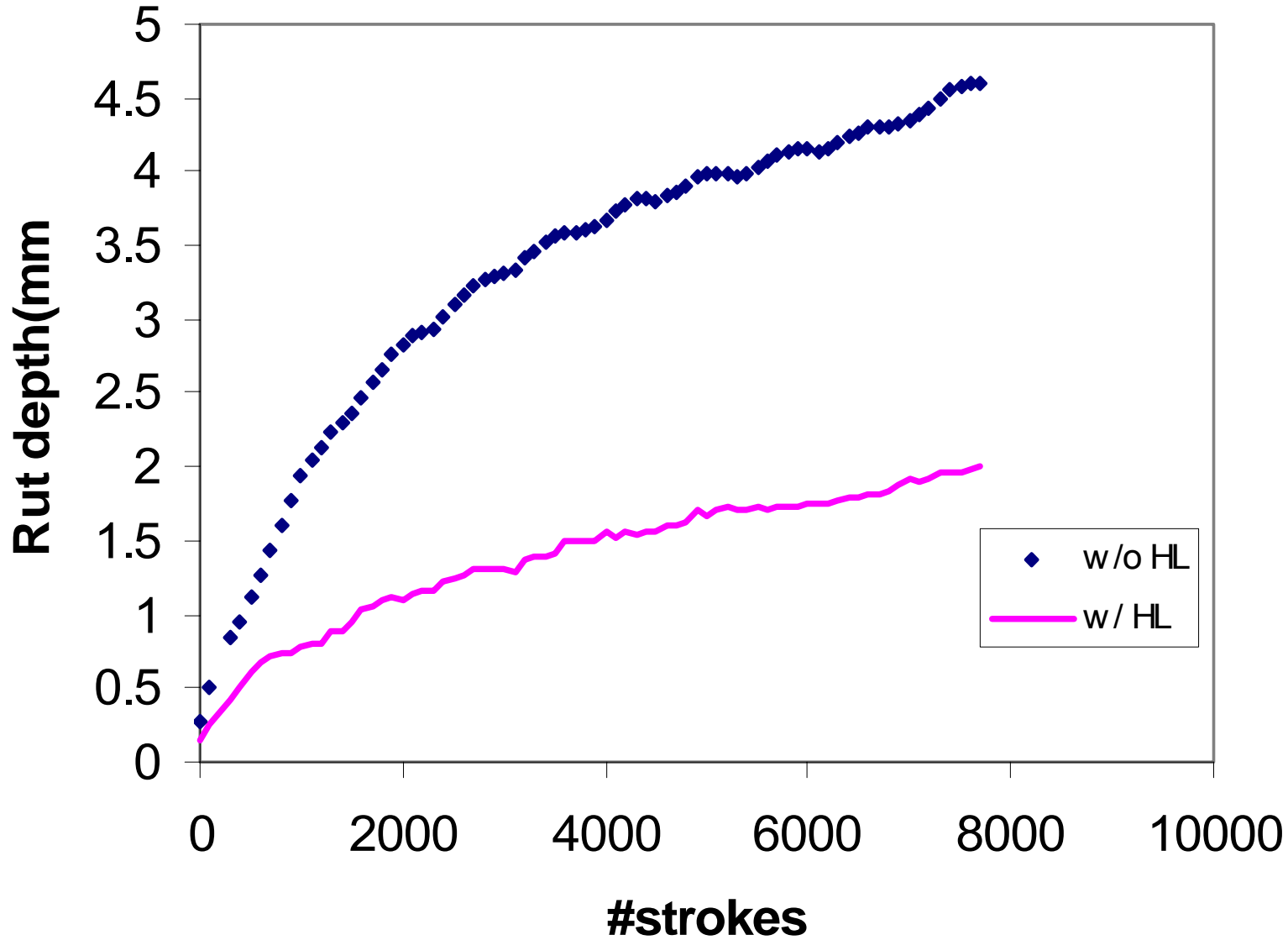
Rut Depth, mm



Granite(2/2)



Sandstone(1/2)



Conclusions

- HL has multifunctional benefits (high temperature active filler, improve low temperature toughness without substantially reducing relaxation, improve moisture resistance)
- The impact of multifunctional benefits reduces damage in mastic (dry and wet)
- HL improves bitument-aggregate bond
- DMA is a reasonable tool to monitor impact of filler on: damage rate as affected by rest periods (healing) and moisture effects

Conclusions, cont'd

- The reduction in the rate of microcrack damage afforded by HL in the mastic and fine aggregate may allow healing to occur for an extended period lengthening fatigue life

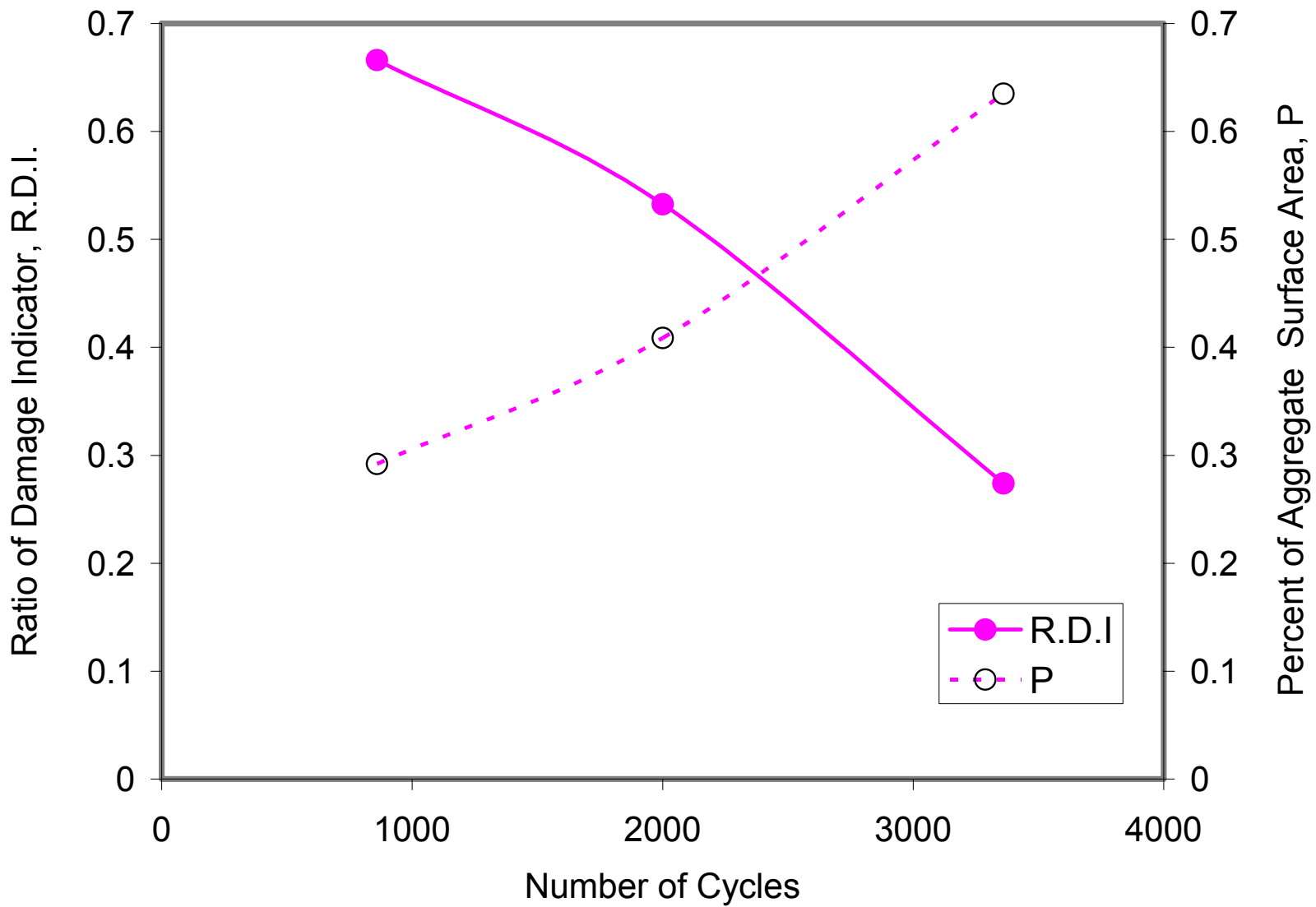
Partially wet bond strength

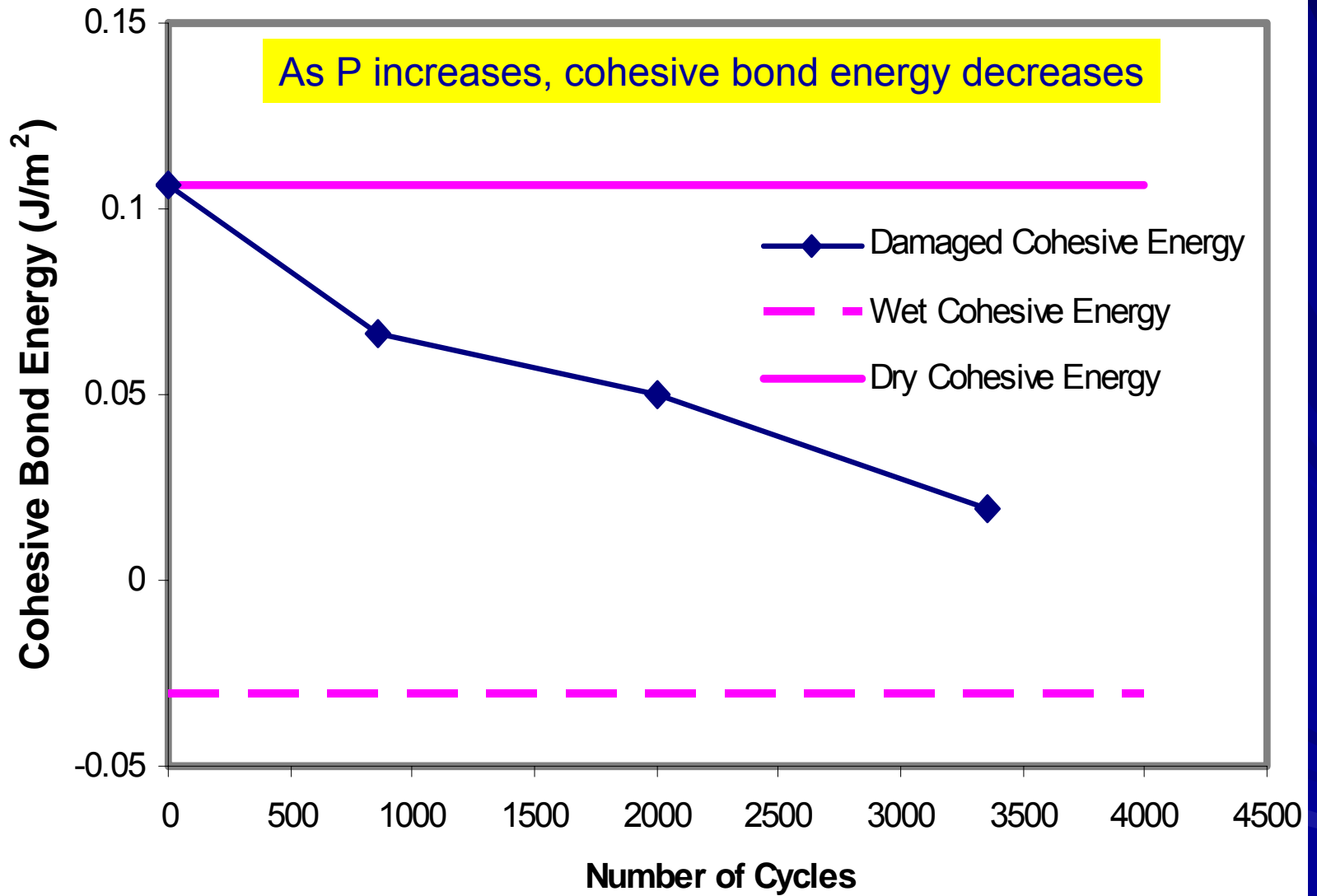
$$\Delta G_{pw}^a = \frac{NS_{i,w}^R}{NS_{i,d}^R} \Delta G_d^a = \Delta G_d^a (1 - P_i) + \Delta G_w^a P_i$$

Ratio of damage indicator (RDI)

Calculation of percent of aggregate surface area affected by water

$$P_i = \frac{\Delta G_d^a \left(\frac{NS_{i,w}^R}{NS_{i,d}^R} - 1 \right)}{\Delta G_w^a - \Delta G_d^a}$$





As P increases, cohesive bond energy decreases

