ALTERNATIVE HMA CHARACTERIZATION FOR M-E PAVEMENT REHABILITATION DESIGN

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Outline

- Objective
- Background (Data Input Level for Rehabilitation Design)
- Approach
  - ✓ Field tests (Previous Study) + Laboratory Tests
- Results
- Findings and Conclusions
- Other Related Efforts

Acknowledgments

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Project Objective

- Determine the in-place HMA layer modulus for Mechanistic-Empirical Pavement Rehabilitation Design
- Verify the MEPDG proposed method for determining the field damaged HMA master curve
- Recommend how to improve it if found not applicable for VA pavements

Background: *Data Input Level 1*

- FWD DATA
  - ✓ Measure deflection
  - ✓ Backcalculate combined HMA modulus (E_i)
- FIELD CORING
  - ✓ Volumetric properties
- UNDAMAGED MASTER CURVE

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right)$$

$$+ \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{-0.603313 - 0.313351\log(f) - 0.393532\log(\eta)}}$$

$$\log\left|E^*\right| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log f_r}}$$

Data Input Level 1 (Cont.)

- **ESTIMATE DAMAGE, dj:**

$$d_j = 1 - \frac{E_i}{E^*}$$

- **DETERMINE α'**

$$\alpha' = (1 - d_j) * \alpha$$

- **COMPUTE FIELD DAMAGED MODULUS**

$$\log\left|E^*\right| = \delta + \frac{\alpha'}{1 + e^{\beta - \gamma \log f_r}}$$

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Data Input Level 2

- **FIELD CORING**
  - ✓ Volumetric Properties

- **UNDAMAGED MASTER CURVE**

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right)$$

$$+ \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{-0.603313 - 0.313351\log(f) - 0.393532\log(\eta)}}$$

$$\log\left|E^*\right| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log f_r}}$$

Data Input Level 2 *(Cont.)*

- **LABORATORY RESILIENT MODULUS, Mr**
- **ESTIMATE DAMAGE, dj:**

$$d_j = 1 - \frac{M_r}{E^*}$$

- **DETERMINE a'**

$$\alpha' = (1 - d_j) * \alpha$$

- **COMPUTE FIELD DAMAGED MODULUS**

$$\log\left|E^*\right| = \delta + \frac{\alpha'}{1 + e^{\beta - \gamma \log f_r}}$$

Data Input Level 3

- **TYPICAL MIX PROPERTIES**

- **UNDAMAGED MASTER CURVE**

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right)$$

$$+ \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{-0.603313 - 0.313351\log(f) - 0.393532\log(\eta)}}$$

$$\log\left|E^*\right| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log f_r}}$$

Data Input Level 3 *(Cont.)*

- DISTRESS/CONDITION SURVEY
  - ✓ Pavement Rating: Excellent, Good, Fair, Poor, Very Poor
- ESTIMATE DAMAGE, d_j:

Category	Damage (d_j)
Excellent	0.00 – 0.20
Good	0.20 – 0.40
Fair	0.40 – 0.80
Poor	0.80 - 1.20
Very Poor	> 1.2

Data Input Level 3 (Cont.)

- **DETERMINE a'**

$$\alpha^{'} = (1 - \mathrm{d}_{\mathrm{j}}) * \alpha$$

- **COMPUTE FIELD DAMAGED MODULUS**

$$\log\left|E^{*}\right| = \delta + \frac{\alpha^{'}}{1 + e^{\beta - \gamma \log f_r}}$$

APPROACH

- From previous study (different sites in VA)
  - ✓ FWD Testing → Backcalculated Moduli
  - ✓ Distress/Condition Survey
  - ✓ Coring + Laboratory Testing
    - Volumetric Analysis and Mr
- Calculate Estimated Undamaged E*
- Calculate Damaged E* for three input levels
- Measure E* in the lab
- Compare

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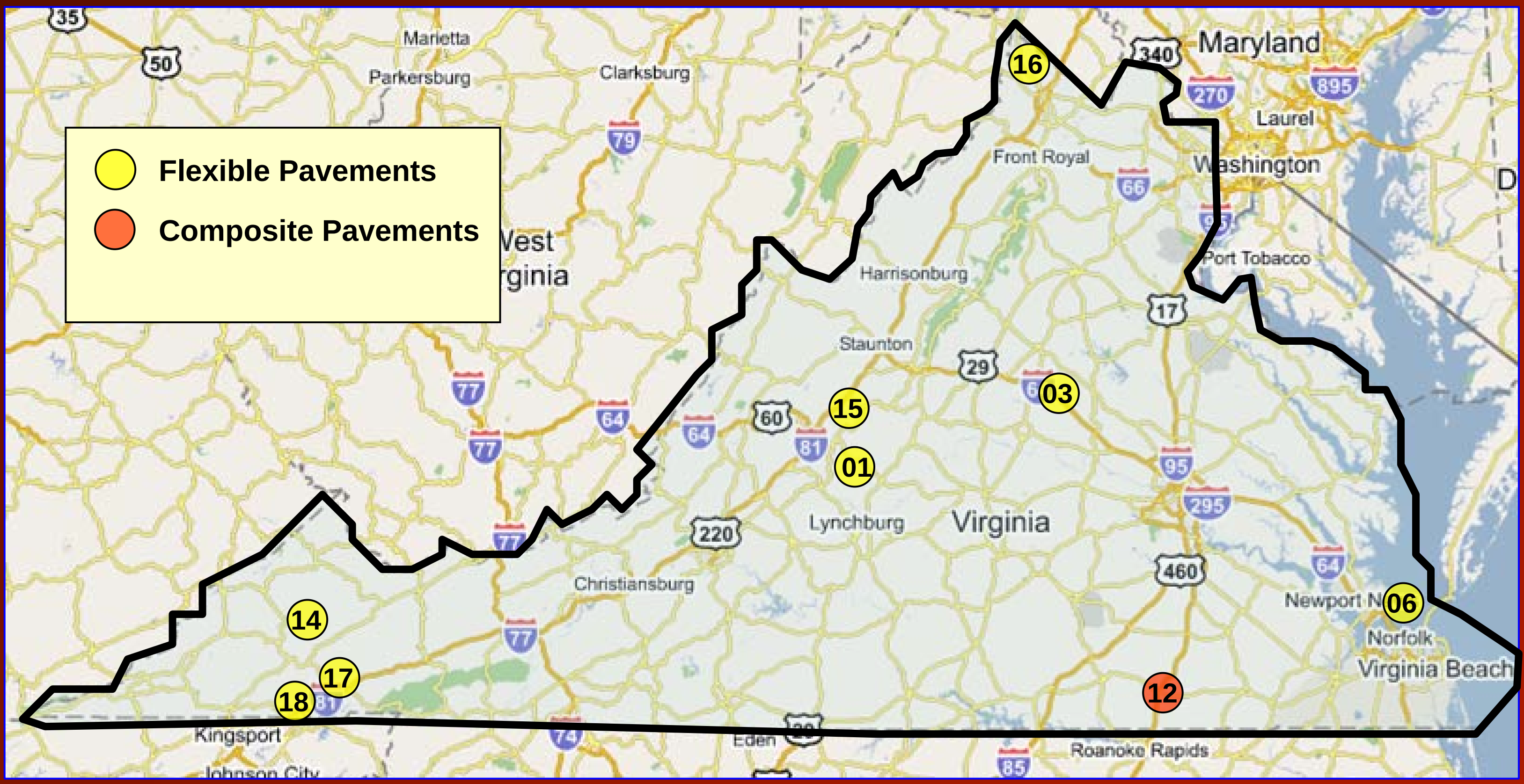
Selected Sites



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Selected Sites *(Cont.)*

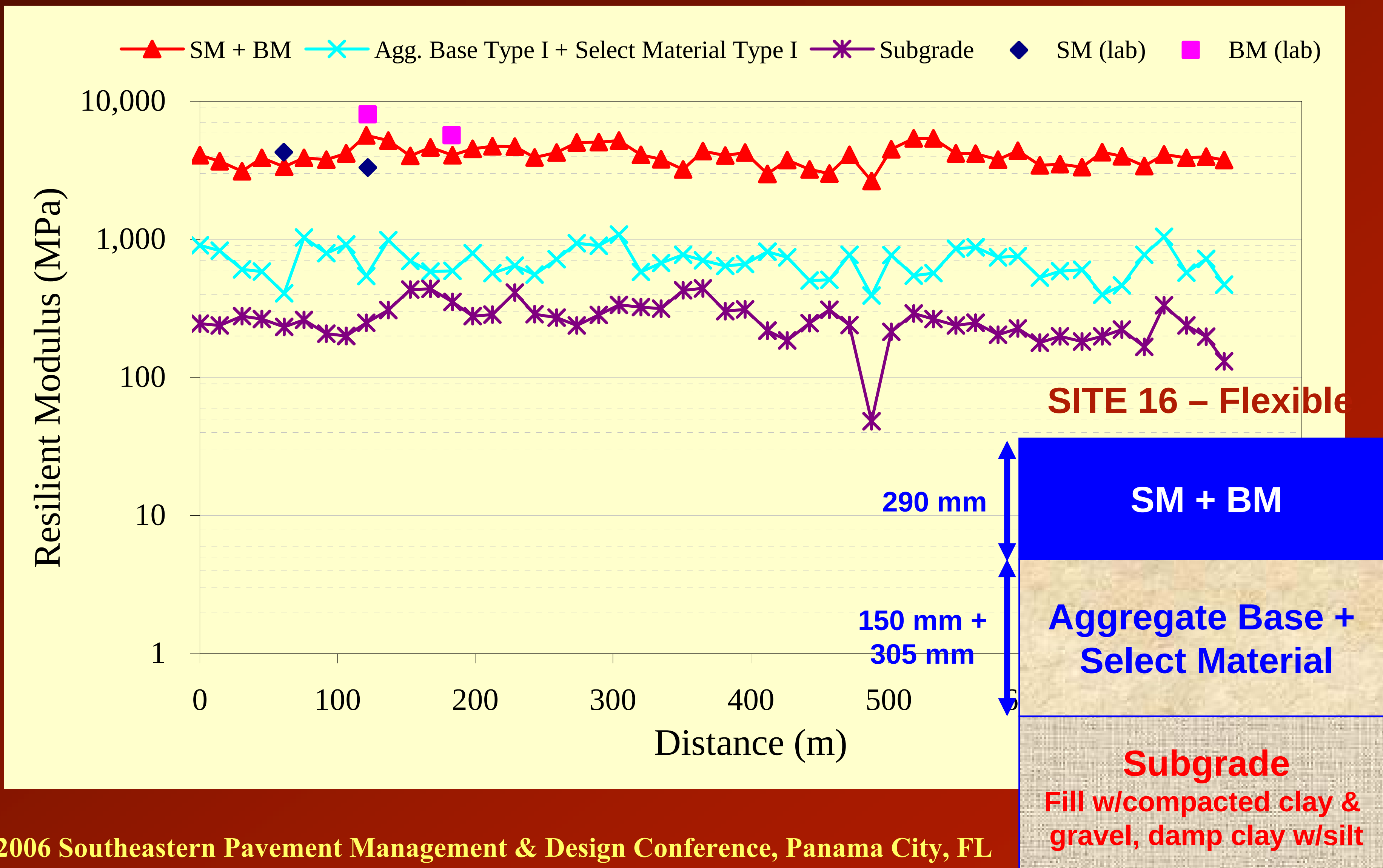
Site	County	Route	Direction	Milepost*	Pavement Type	Pav. Age/ Surf.
1	Amherst	US-29	South	7.80-7.30	Flexible	34 / 11
3	Louisa	I-64	West	9.91-9.41	Flexible	34 / 9
6	York	I-64	West	2.62-2.12	Flexible	25 / 7
12	Greensville	I-295	North	5.50-6.00	Comp. JPCP (rehab)	14 / 6
14	Russell	I-19	North	8.68-9.18	Flexible	6 / 6
15	Rockbridge	I-81	South	22.92-22.42	Flexible	37 / 17
16	Frederick	I-81	North	21.31-21.87	Flexible	39 / 13
17	Washington	I-81	South	12.50-12,00	Flexible	42 / 11
18	Washington	I-81	South	1.50-1.00	Flexible	5 / 3

Field Data Collection

FWD Testing

- **Test pattern dependent on pavement structure**
- **Basin Testing**
  - ✓ **4 load levels and 3 drops per load level**
  - ✓ **50 foot intervals in OWP (AC surface)**

FWD Analysis: Flexible Site 16

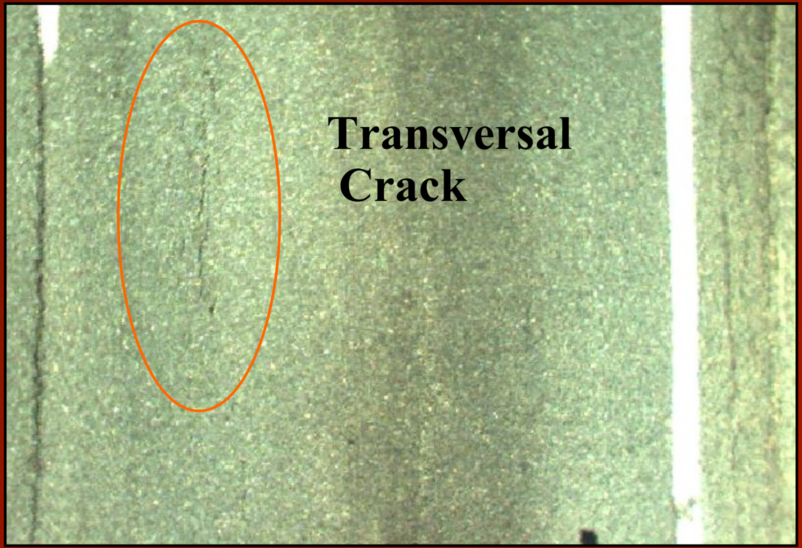


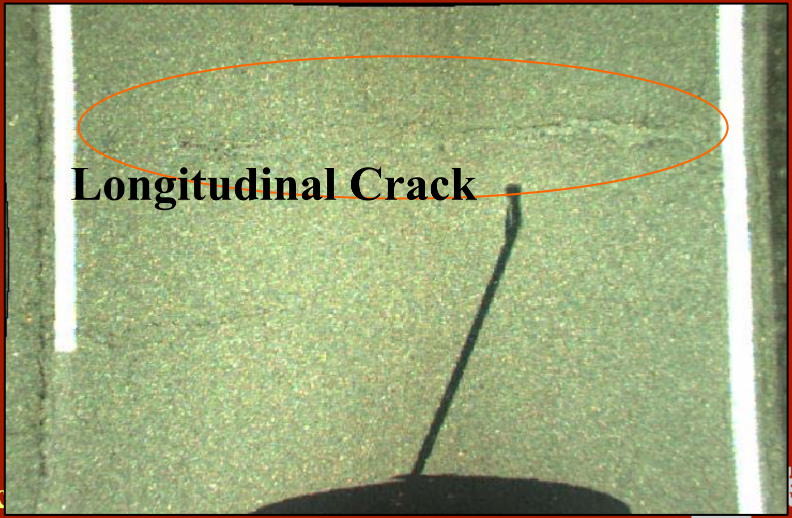
Coring and Boring

- Retrieve pavement materials samples for laboratory testing
- Number of tests varied based on pavement type
- Controlling factor was amount of lane closure time

Distress Survey

VT Digital Camera System





Pavement Condition

Site	NDR	LDR	CCI
1	74.5	96.7	**75**
3	68.6	95.8	**69**
6	80.5	96.3	**81**
12	97.2	95.8	**96**
14	99.9	99.9	**100**
15	92.3	89.7	**90**
16	91.6	99.8	**92**
17	92	94.2	**92**
18	100	100	**100**

Other Measurements…

Laboratory Tests

- Specimen preparation
  - ✓ Core 6” cores to 4”
  - ✓ Cut the ends

- Dynamic Modulus
  - ✓ 5 Temperatures: 10°F, 40°F, 70°F, 100°F, 130°F
  - ✓ 6 Frequencies: 0.1Hz, 0.5Hz, 1Hz, 5Hz, 10Hz, 25Hz

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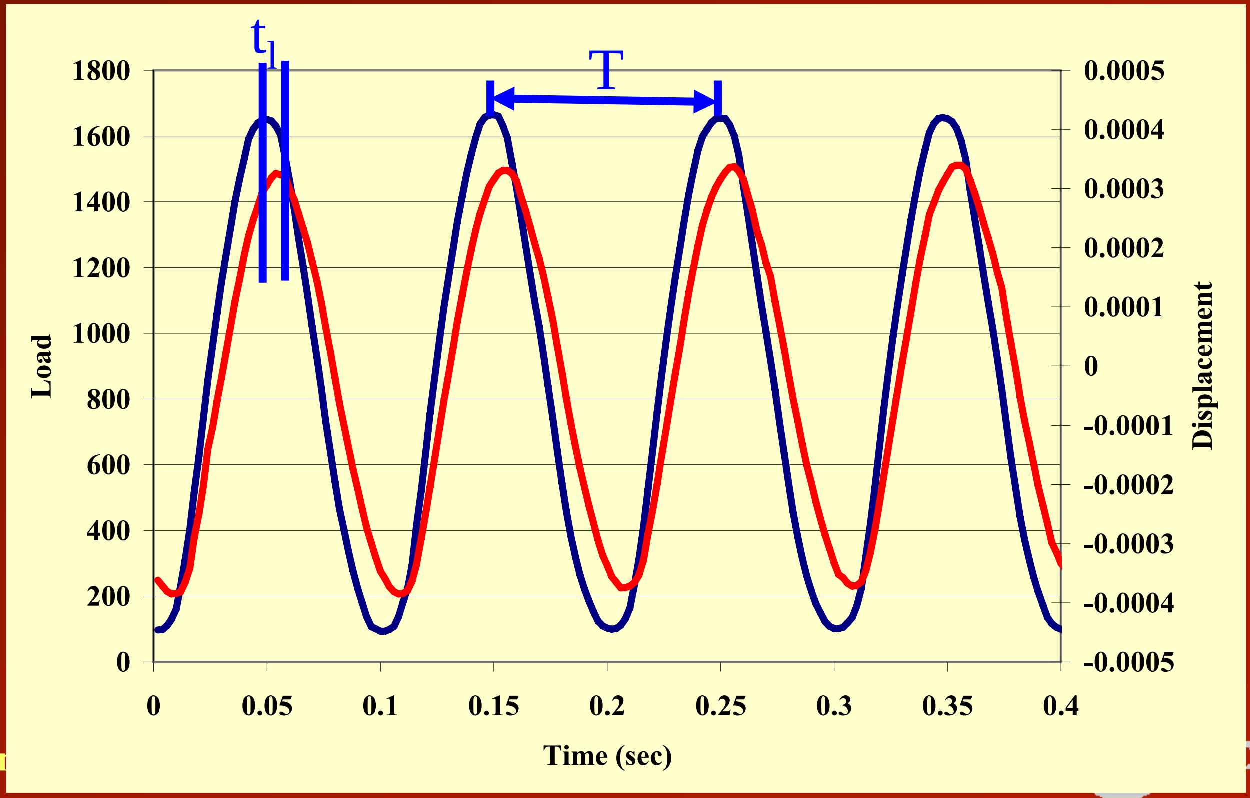
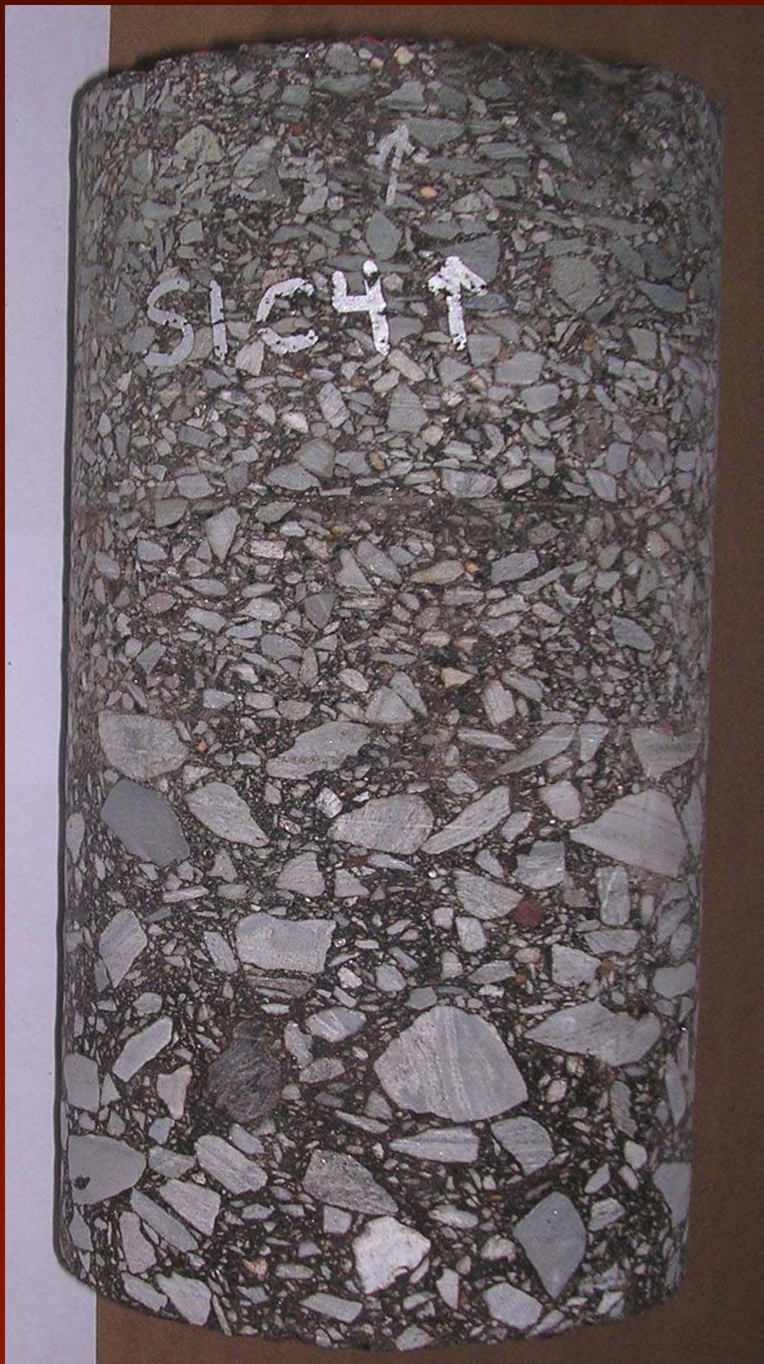
Dynamic Modulus

$$\left|E^*\right| = \frac{\sigma_0}{\varepsilon_0} \qquad E^* = E' + iE'' \qquad E^* = \left|E^*\right|(\cos\phi + i\sin\phi)$$

$$\phi\,(\text{degrees}) = \frac{\text{time lag}}{\text{Period}}\,360$$



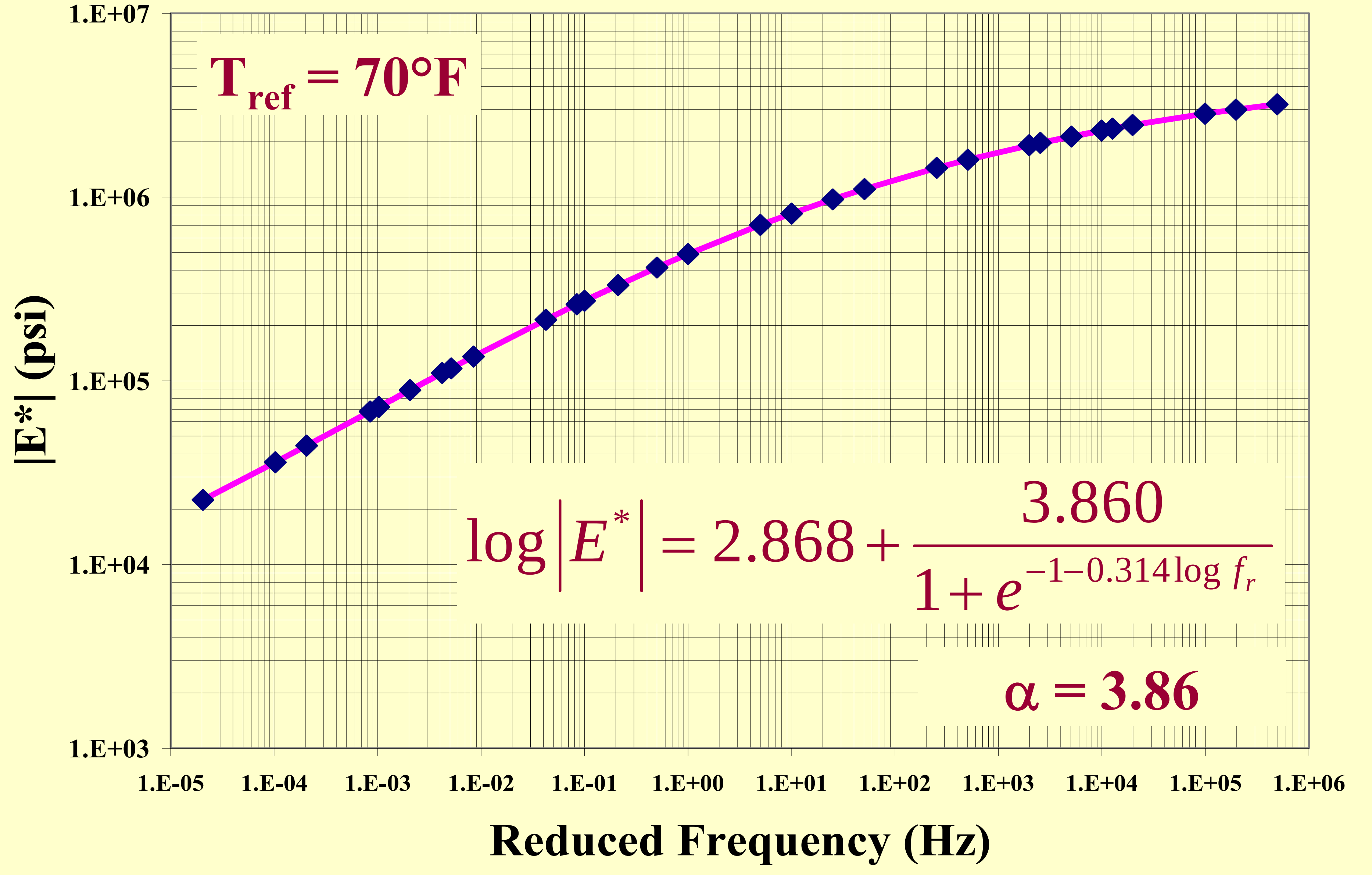
SITE 01



Results: Site 01 (Core S01C4)

- **Volumetric Analysis**
  - ✓ **Ignition**
  - ✓ **Gradation**
- **Undamaged E***
  - ✓ **Witczak equation**

Estimated Undamaged Master Curve



Data Input Level 1

- **Backcalculated Modulus:**
  - ✓ **E (avg.) = 462ksi, Avg. Temp. = 74.2°F**

- **Undamaged E* @ 5Hz, 74.2°F = 672ksi**

$$d_j = 1 - \frac{462}{672} = 0.31$$

$$\alpha' = 0.69 * 3.86 = 2.66$$

Data Input Level 2

- **Resilient Modulus**
  - ✓ **Mr (Wearing Surface) = 746ksi**
  - ✓ **Mr (Base) = 433ksi**

$$M_{rc} = 569$$

$$M_{rc} = \left(\frac{h_1 \sqrt[3]{M_{rWS}} + h_2 \sqrt[3]{M_{rBM}}}{h_1 + h_2}\right)^3$$

  - ✓ **Undamaged E* @ 1.6Hz, 77°F = 468ksi**

$$d_j = 1 - \frac{569}{468} = -0.22$$

$$\alpha' = 1.22 * 3.86 = 4.71$$

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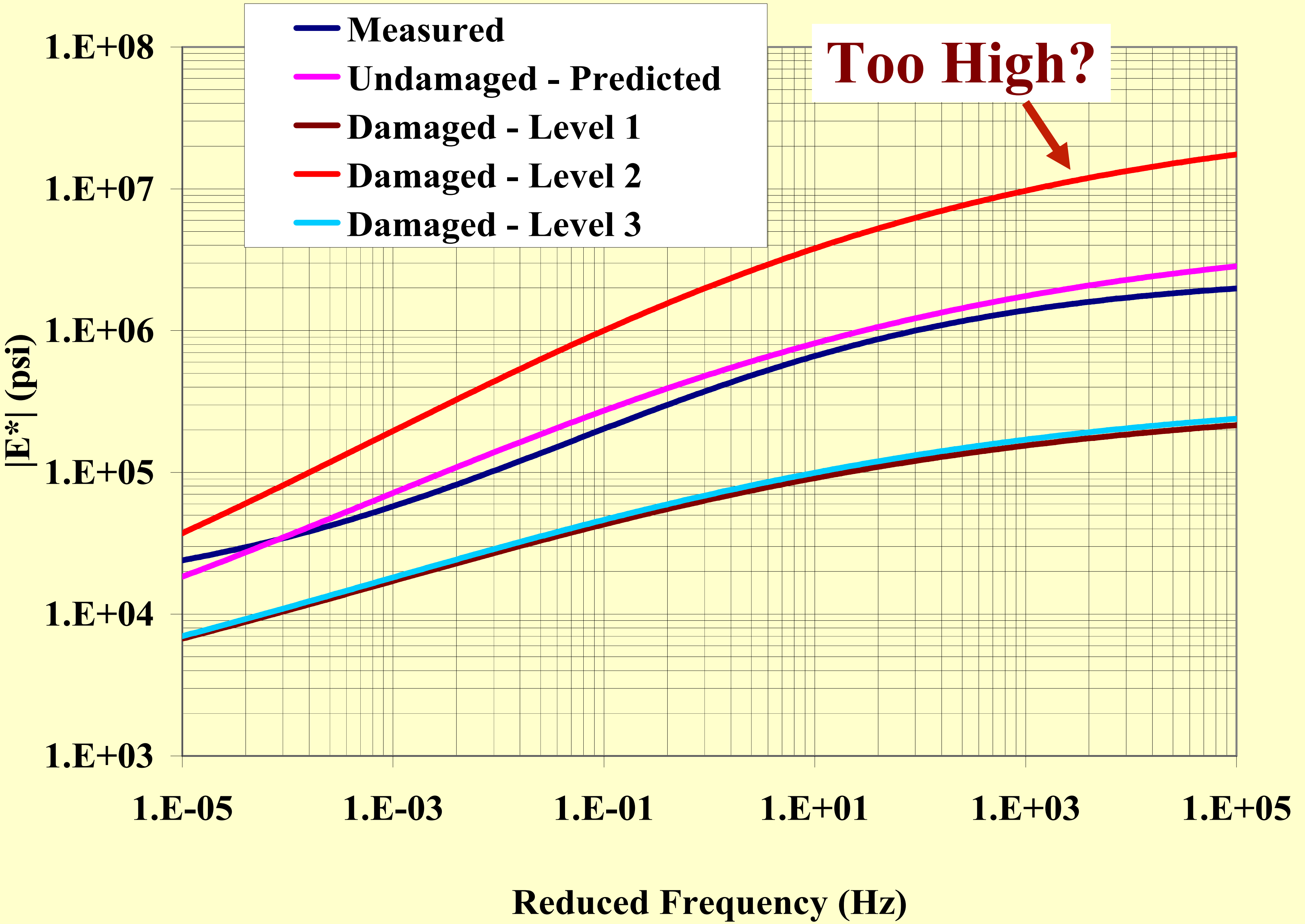
Data Input Level 2

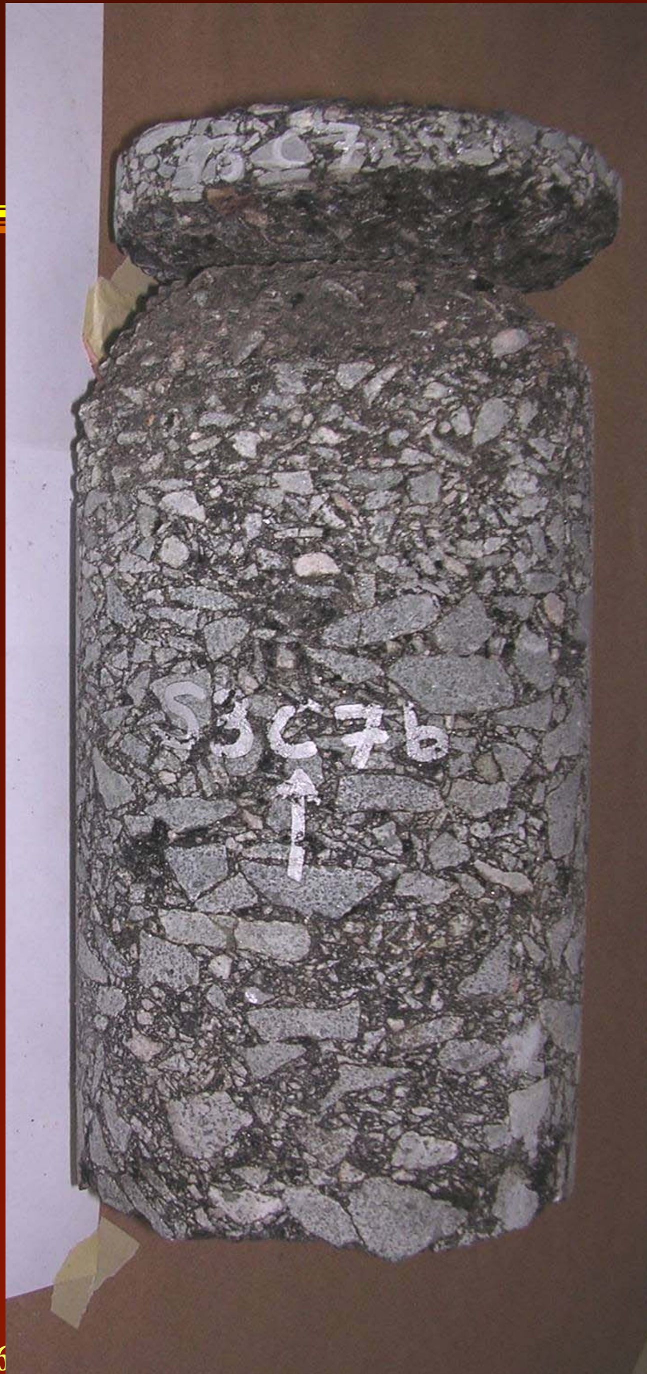
- **NDR = 74.5 LDR = 96.7 CCI = 75**
- **Rating = Good**

$$d_j = 0.3$$

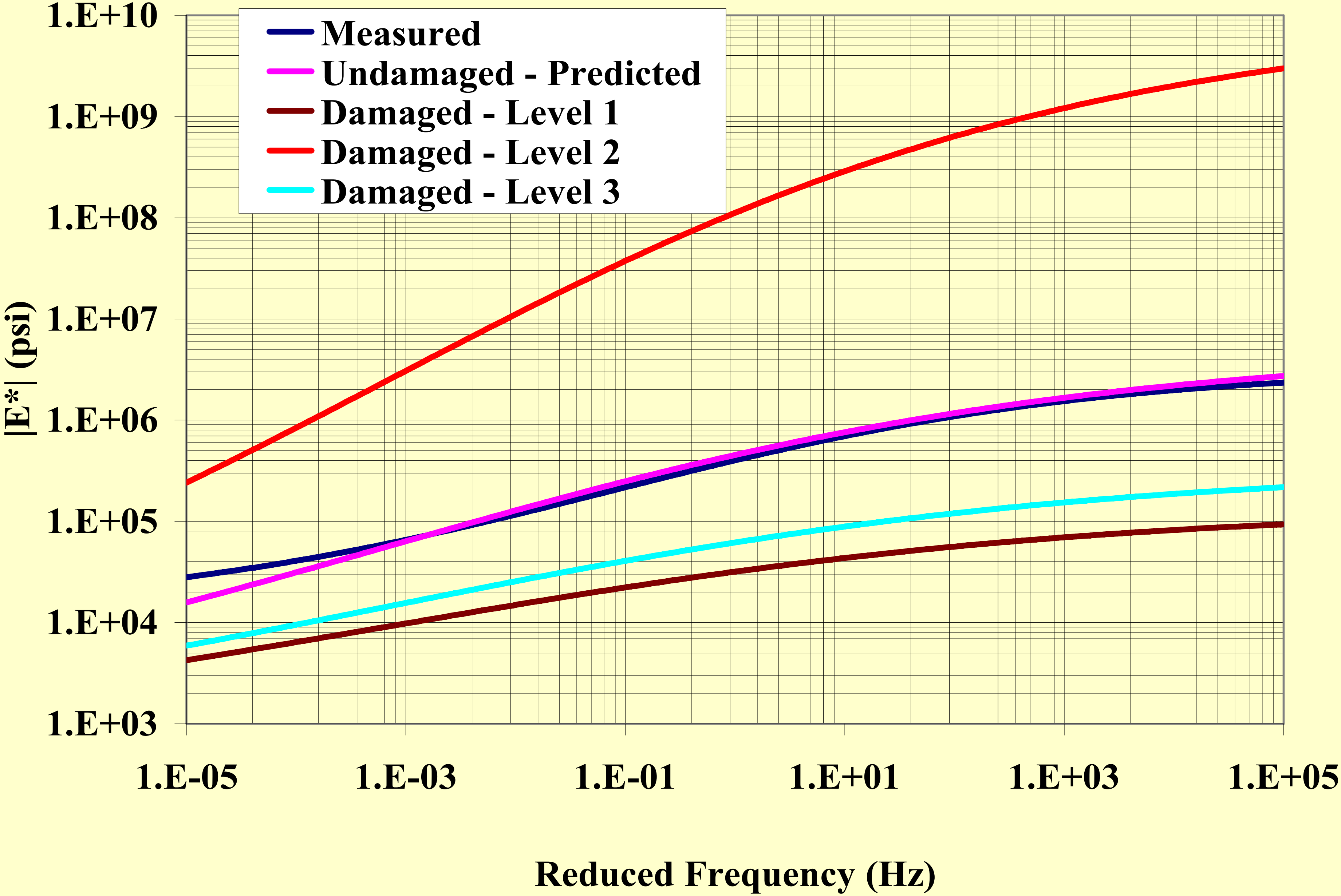
$$\alpha' = 0.7 * 3.86 = 2.7$$


Measured
Undamaged - Predicted
Damaged - Level 1
Damaged - Level 2
Damaged - Level 3
Too High?
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
|E*| (psi)
1.E-05
1.E-03
1.E-01
1.E+01
1.E+03
1.E+05
Reduced Frequency (Hz)

SITE 03



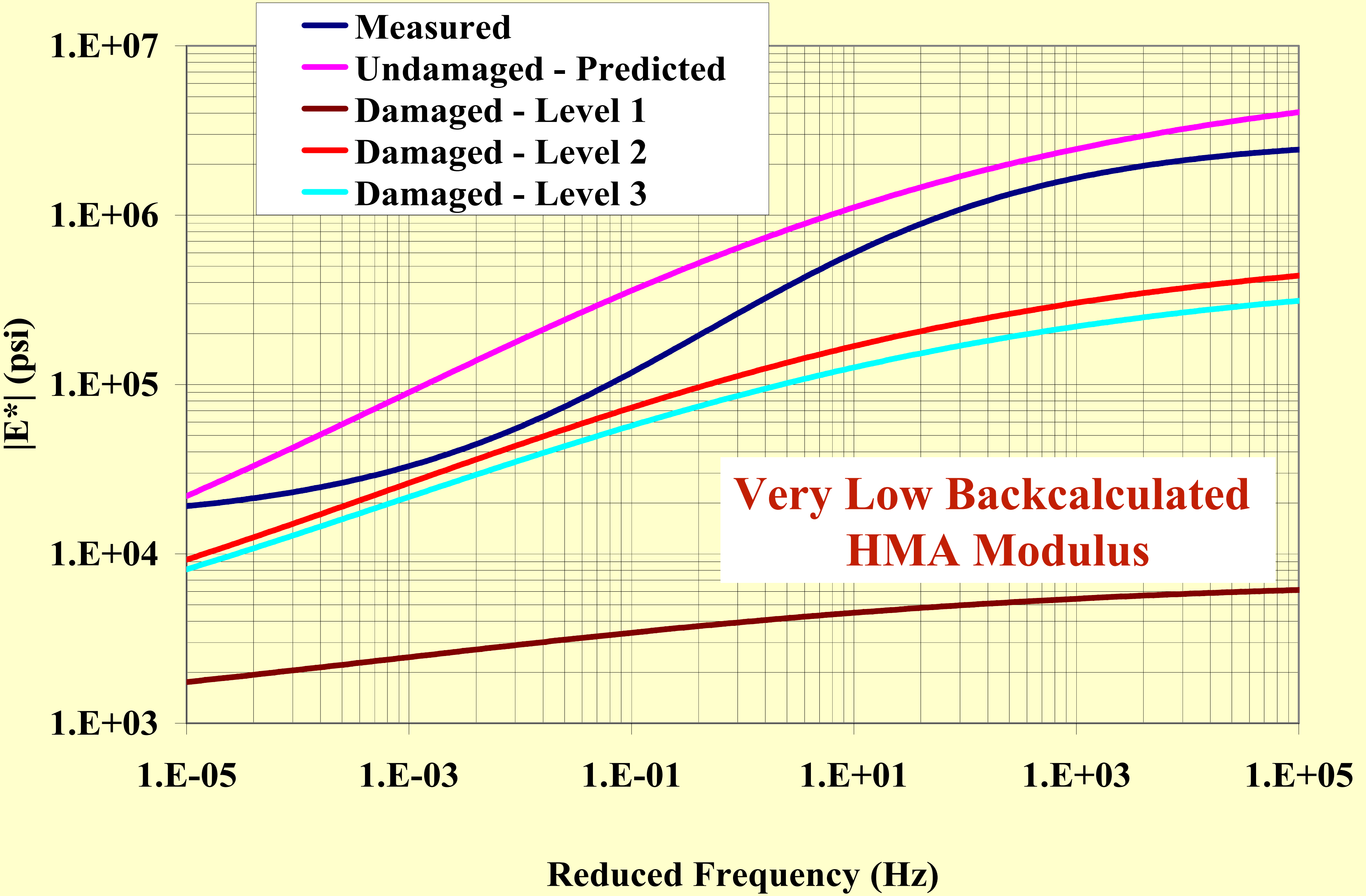
S03C7



Measured
Undamaged - Predicted
Damaged - Level 1
Damaged - Level 2
Damaged - Level 3
1.E+10
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
|E*| (psi)
1.E-05
1.E-03
1.E-01
1.E+01
1.E+03
1.E+05
Reduced Frequency (Hz)

SITE 06

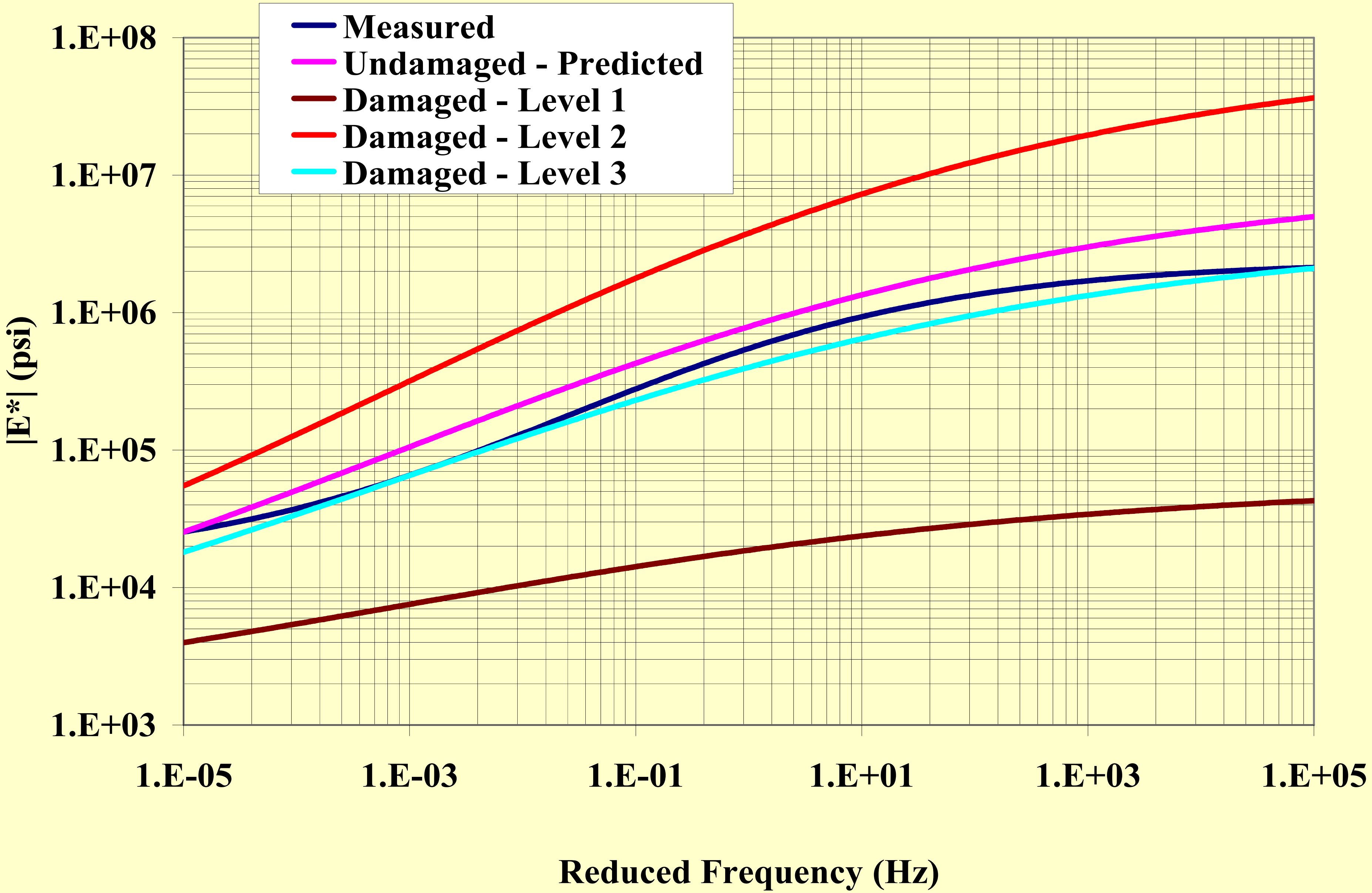
S06C1



Measured
Undamaged - Predicted
Damaged - Level 1
Damaged - Level 2
Damaged - Level 3
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
|E*| (psi)
Very Low Backcalculated HMA Modulus
1.E-05
1.E-03
1.E-01
1.E+01
1.E+03
1.E+05
Reduced Frequency (Hz)

SITE 12

S12C2


Measured
Undamaged - Predicted
Damaged - Level 1
Damaged - Level 2
Damaged - Level 3
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
|E*| (psi)
1.E-05
1.E-03
1.E-01
1.E+01
1.E+03
1.E+05
Reduced Frequency (Hz)

Findings

- Volumetric properties from the same site were different from core to core, which resulted in different measured dynamic modulus
- Sigmoidal function provides a very good fit to the dynamic modulus master curve

Findings *(Cont.)*

- Laboratory-measured resilient modulus test does not give a good indication of the combined behavior of thick HMA layers
- Using the average values for the backcalculated FWD may not provide the best estimates for the damage factor

Findings (Cont.)

- The Witczak prediction equation gives reasonable values for the dynamic modulus
  - ✓ Same order of magnitude as the measured ones
  - ✓ In most cases: $0.3 < E_{predicted}/E_{measured} < 1.8$

Findings (Cont.)

- The use of level 3 data on previously overlaid pavements may be misleading because the surface condition does not reflect the overall condition of the entire HMA layer

CONCLUSIONS

- Level 2, as currently used in the proposed M-E Pavement Design Guide, provides unreasonable values for the damaged dynamic modulus master curves
  - ✓ Linked to the method used to measure the Resilient Modulus?

CONCLUSIONS

- Level 1 data is necessary to obtain reliable estimates of the properties of the existing HMA layers.
  - ✓ FWD testing appears to be the only reliable procedure that can measure the overall condition of the entire HMA layer

RECOMMENDATIONS

- **VDOT should not use level 2 type of input for rehabilitation when the proposed ME guide is implemented**
- **Perform sensitivity analysis on the effect of the existing HMA layer dynamic modulus values on the overlay design**

Related Projects

- Catalog of HMA properties for MEPDG
  - ✓ 3 surface, 4 intermediate & 4 base mixes
  - ✓ Dynamic Modulus
  - ✓ Creep
  - ✓ Resilient Modulus
  - ✓ IDT
- Distress Model Calibration (pending approval)
- …

Questions?