# *Factors Influencing the Permeability of Hot-Mix Asphalt Mixtures*

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# Presentation Outline

- Introduction and Background
- Permeability
- Air Voids Measurements
- Results
- Prediction Models
- Summary and Conclusion

# What Is Permeability?

- Important characteristic of asphalt mixtures
  - Drainability characteristics
- Defined as rate of flow of a fluid through a material based on Darcy's Law
  - $Q=KA(h_1/h_2)/L$

# *Properties that Affect Permeability*

- Aggregate size, shape, and gradation
- Air Voids
  - Effective porosity

# Effective Porosity

- **Definition:**
  - Percentage of water permeable voids
- **Importance of Effective Porosity:**
  - Defining durability
  - Assessment of water damage

# *How is Permeability Measured?*

- Laboratory permeability tests
  - Falling-head
  - Constant-head
- Field permeability test

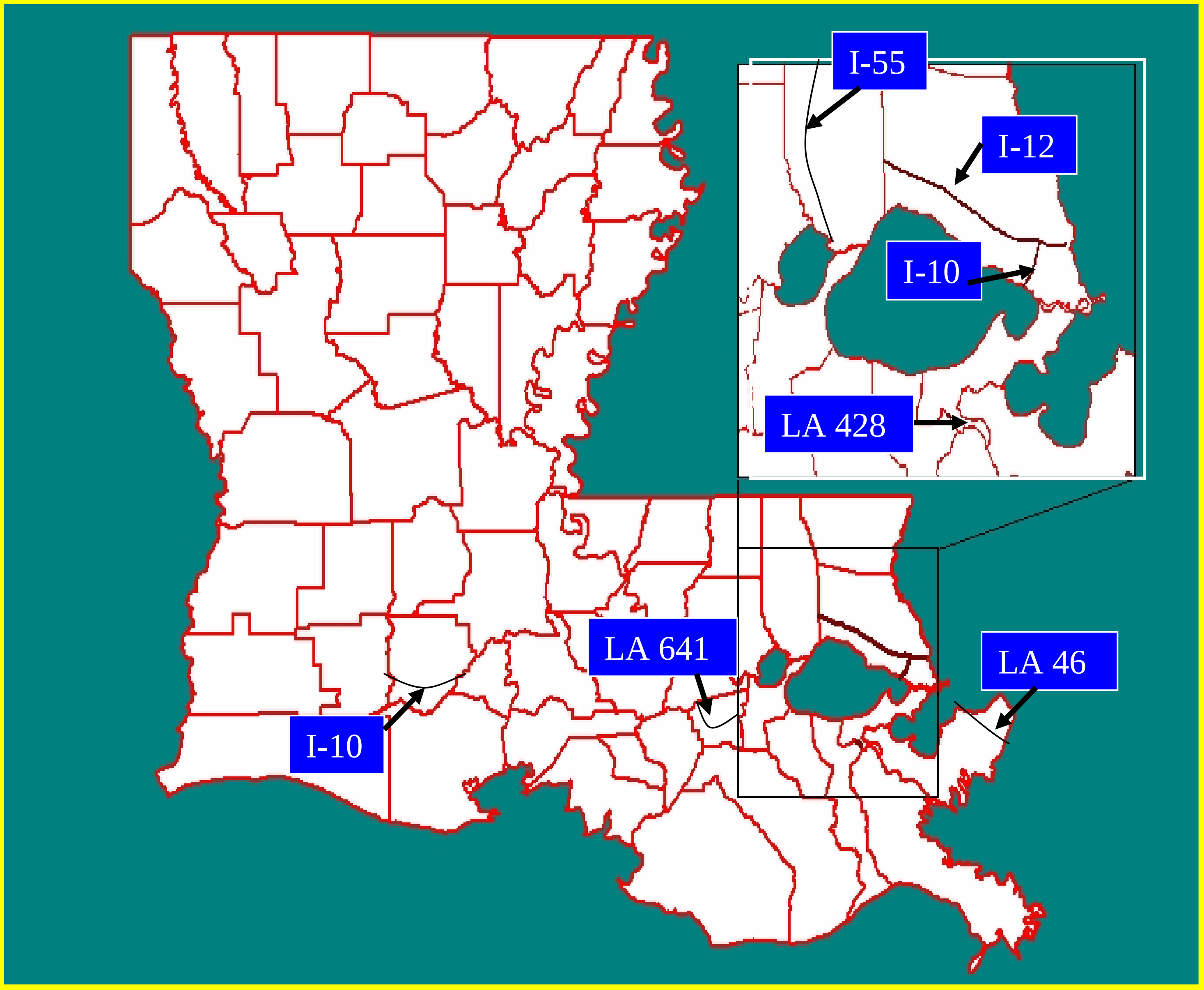
# *Air voids vs Permeability*

- Generally, ***permeability*** of asphalt mixtures is assumed proportional to air void of compacted asphalt mixtures
- High air voids in a pavement allow:
  - water to enter and cause stripping damage

# OBJECTIVES

- Compare air voids estimated from:
  - AASHTO T166, vacuum sealing, gamma ray, effective porosity
- Evaluate the relationships among
  - Permeability, air voids, and effective porosity
- Develop permeability prediction models
  - K=f(Air voids, effective porosity, and gradation characteristics)

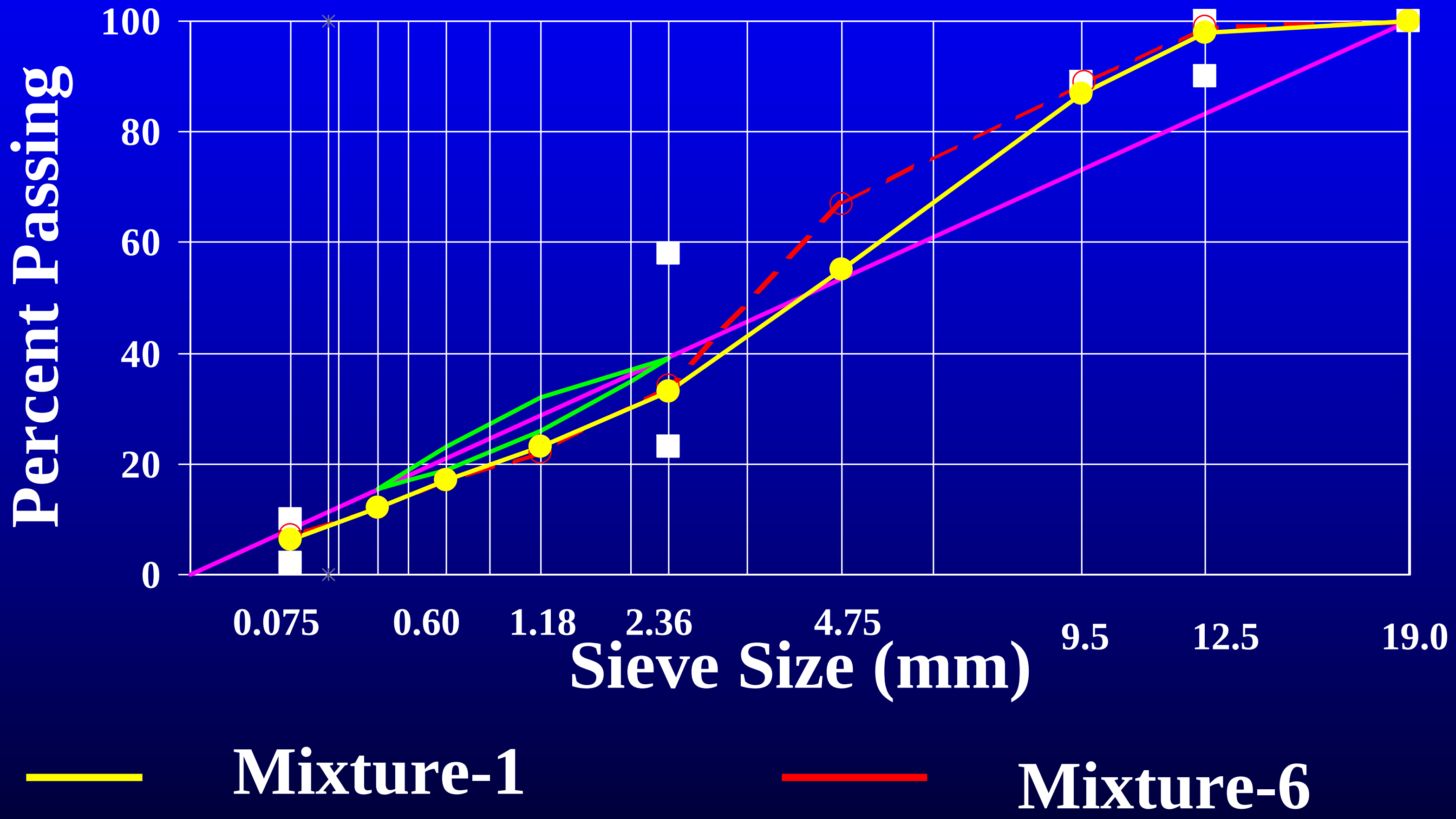
# SCOPE



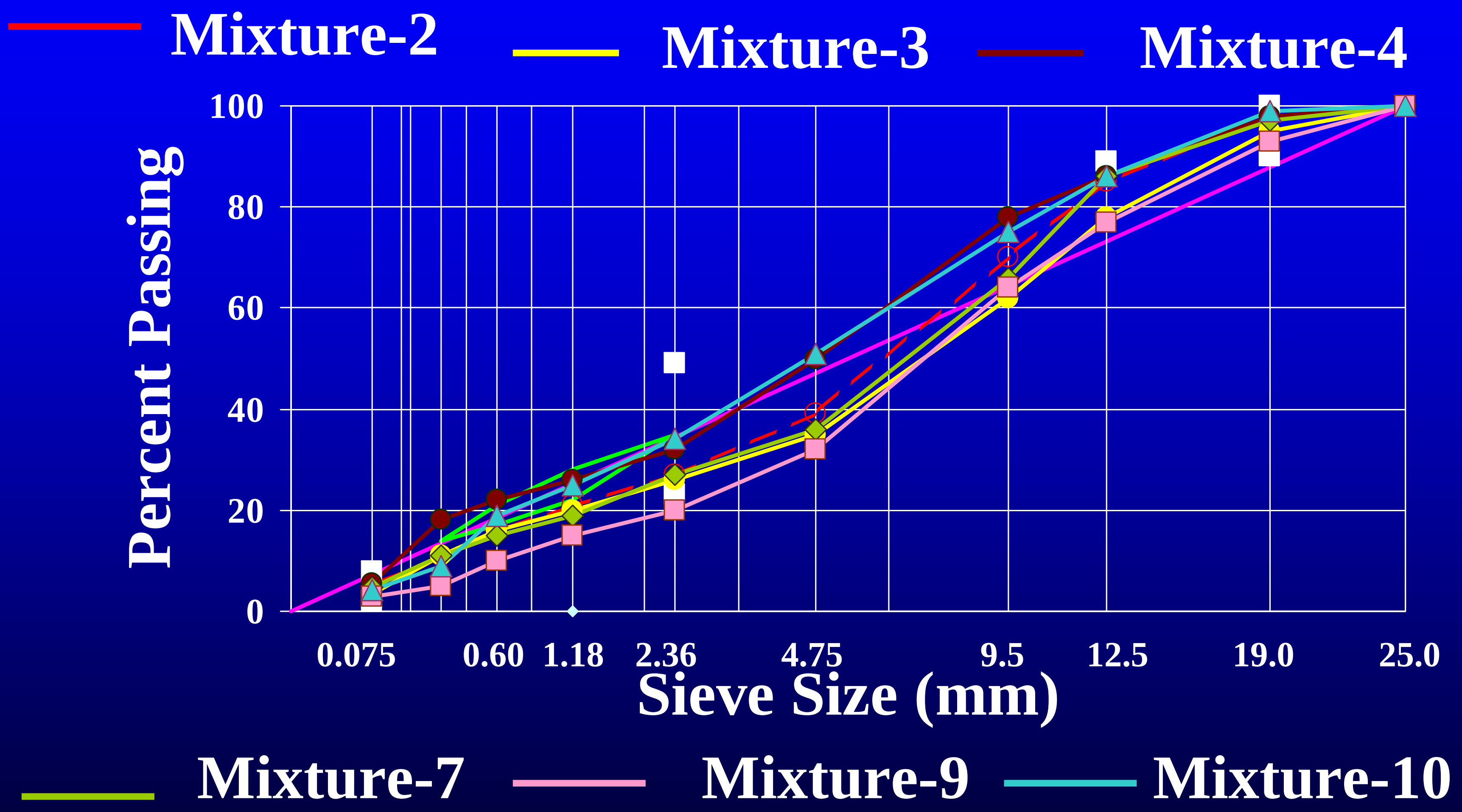
# *Scope*

- 10 Total Mixtures
  - Mixture Types:
    - 8 Superpave and 2 Marshall
  - Design Levels:
    - Level 1: 1
    - Level 2: 1
    - Level 3: 6+2
  - Nominal Maximum Aggregate Sizes:
    - ½” NMS: 2
    - ¾” NMS: 6
    - 1” NMS: 2
  - Grade Types:
    - 8 Wearing Coarse and 2 Binder Coarse
  - Aggregate Gradation Types:
    - 6 Coarse-Graded, 4 Fine-Graded
- In general, triplicate sets of samples were tested

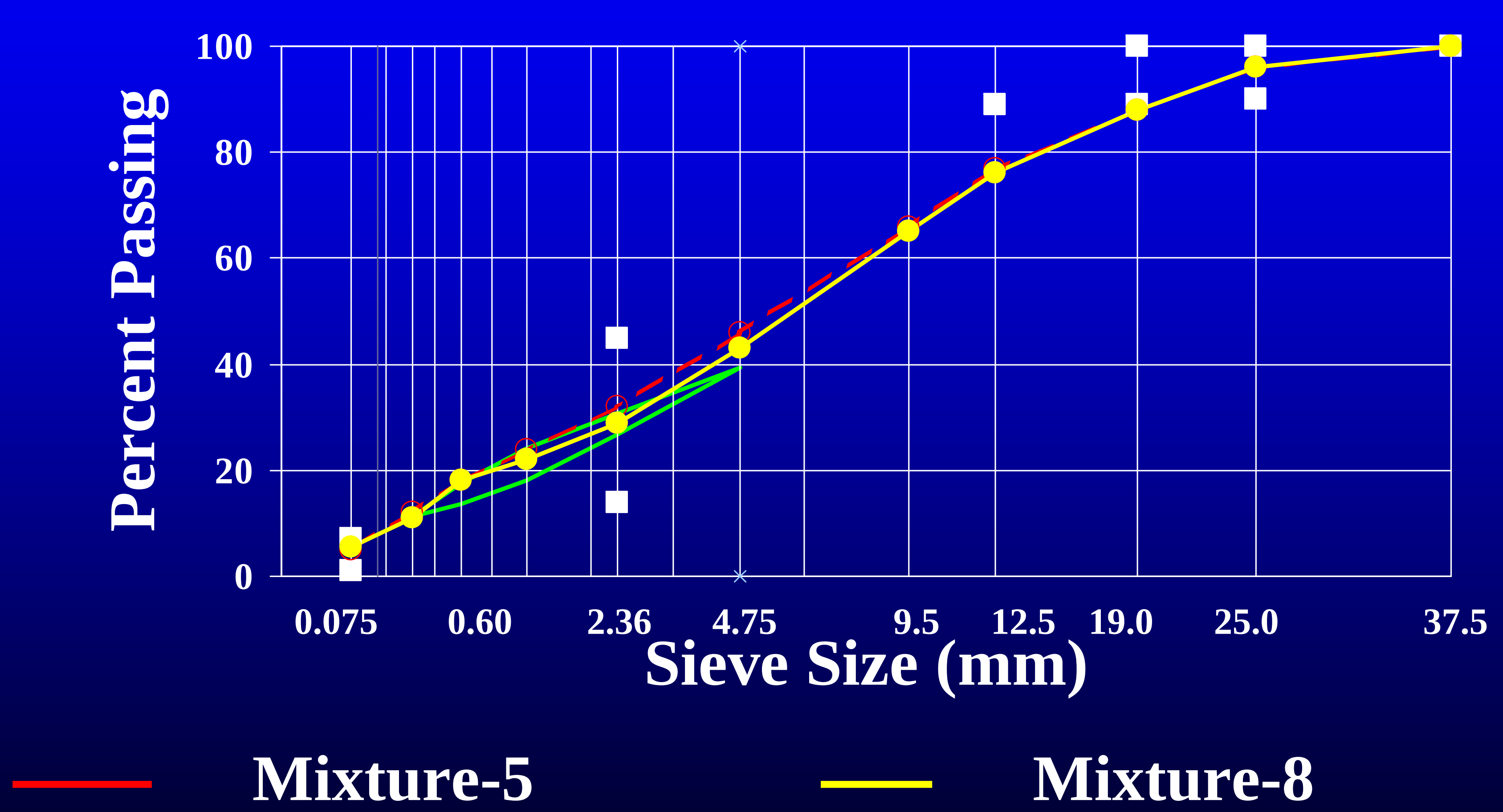
# Gradation Chart for 12.5 mm



# Gradation Chart for 19.0 mm



# Gradation Chart for 25.0 mm



# Experimental Program

- Samples
  - quality acceptance field cores
- Air void measurements
- Permeability testing

# Air Voids Measurement

- Conventional
- Vacuum Sealing
- Gamma Ray

# Conventional Air Void (AASHTO T166) Test

Dry Weight

Submerged Weight

SSD Weight

# Vacuum Sealing Method (Air Void)

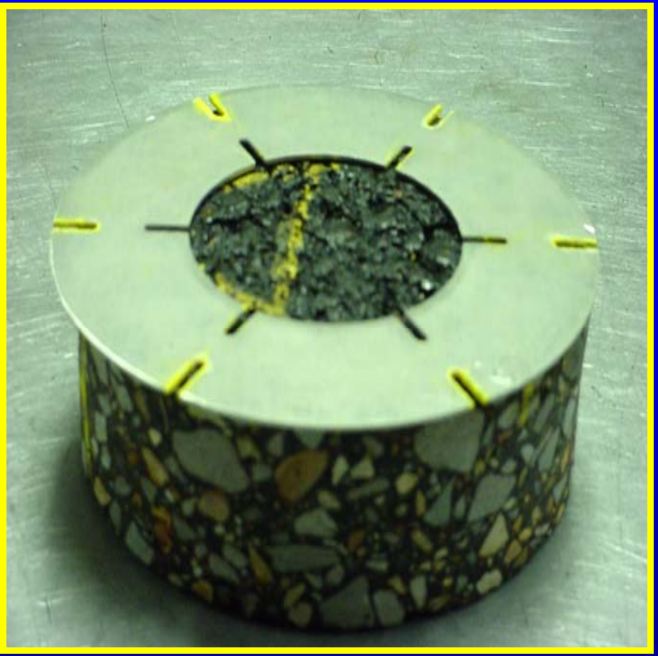
Dry
Weight


Vacuum
Sealing
Device


Vacuum
Sealing

Submerged
Weight

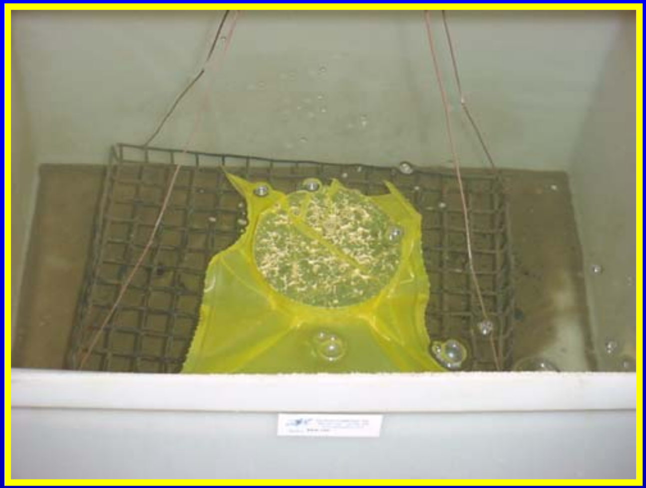
# *Gamma Ray Method (Air Void)*



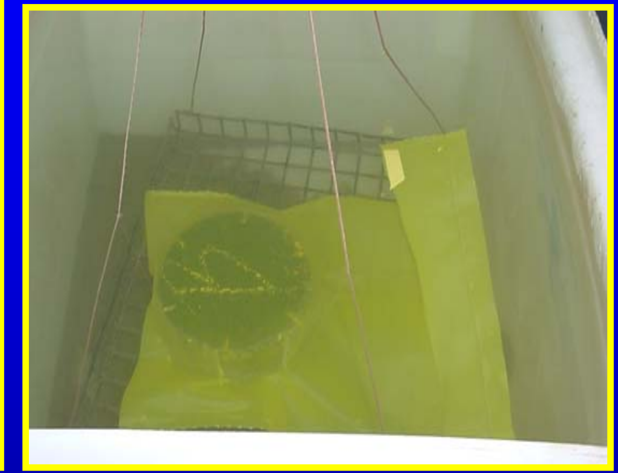
# Effective Porosity Procedure

Dry weight


Vacuum sealing



Submerged weight



Submerged sample weight with the open bag

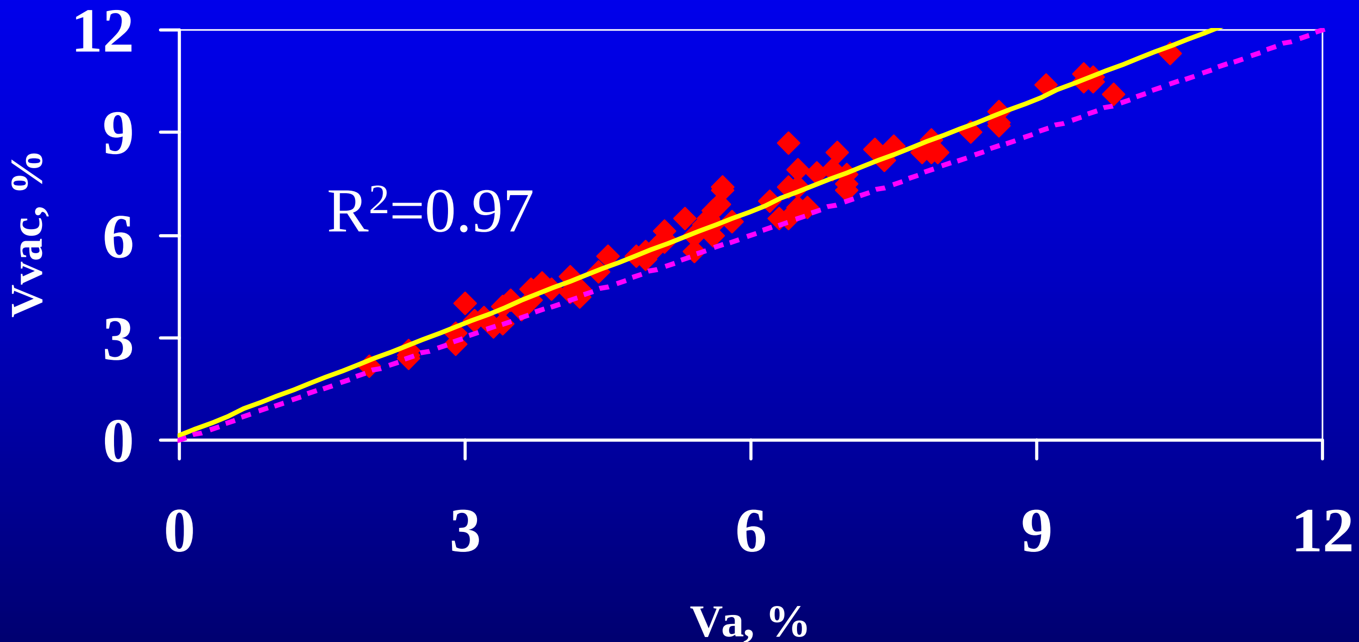
# *Laboratory Permeability*

- Falling head
- ASTM PS –129
- Karol-Warner permeameter

# Permeability Procedure

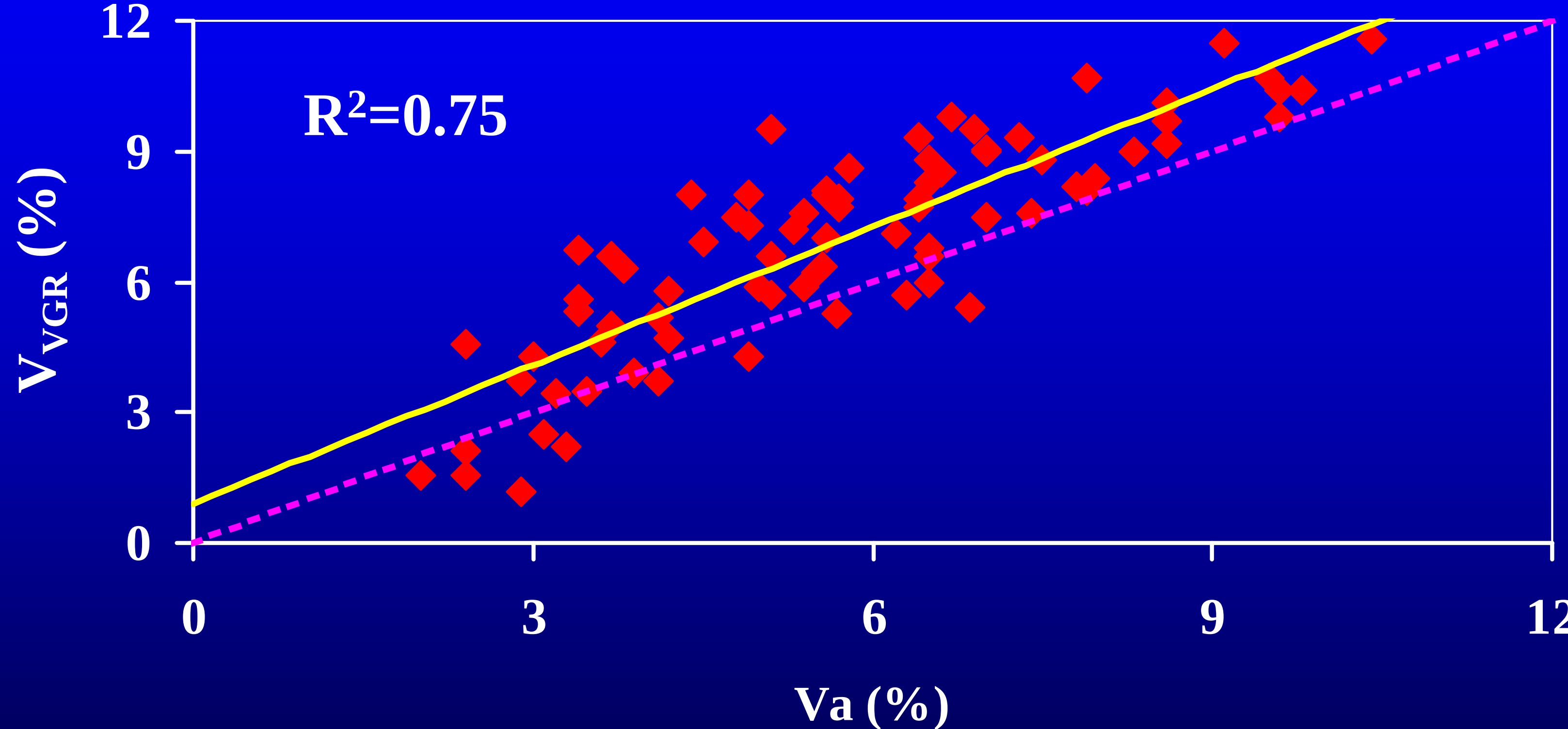
# Discussion of Results

# Conventional($V_a$) vs. Vacuum Sealing ($V_{VAC}$)



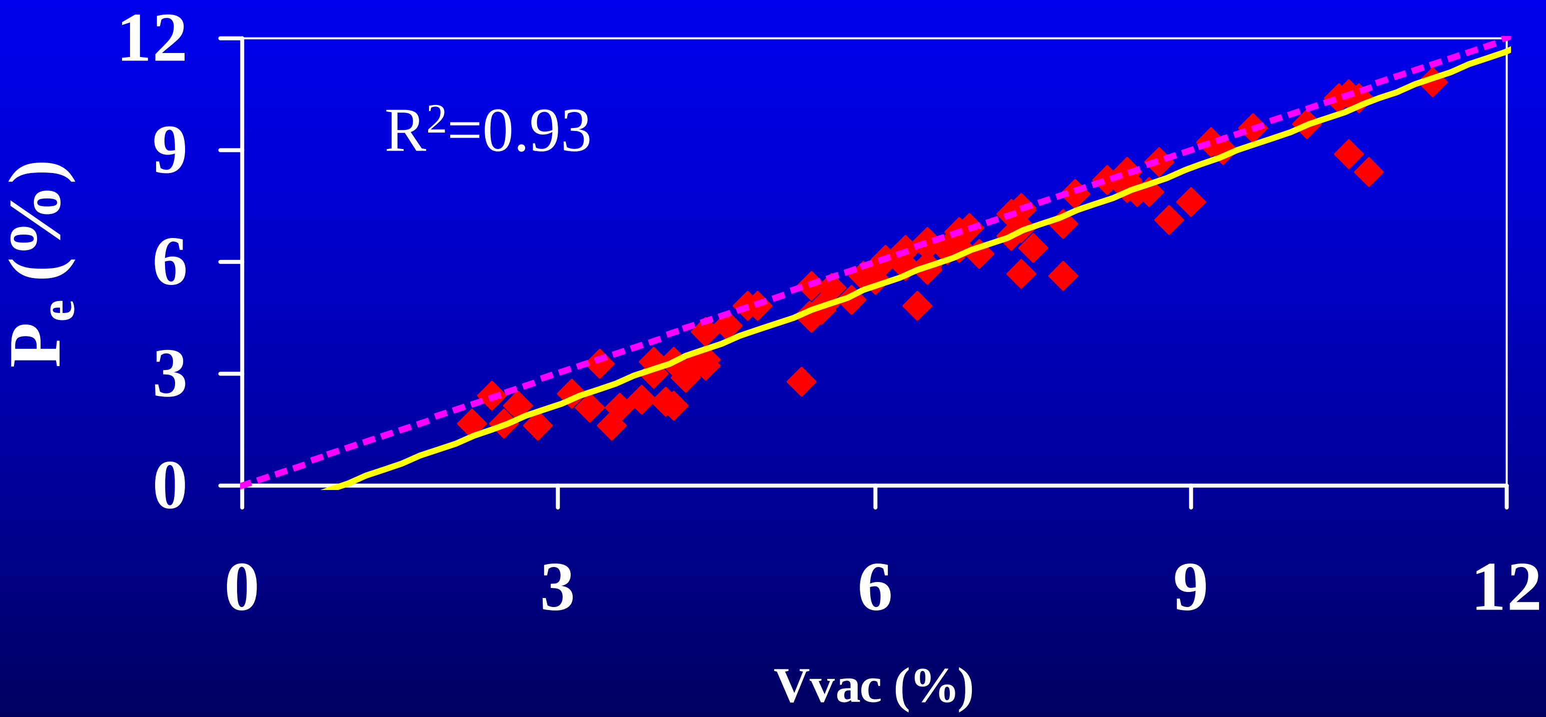

$$V_{VAC} = 1.1V_a + 0.2$$

# Conventional ($V_a$) vs. Gamma Ray ($V_{VGR}$)



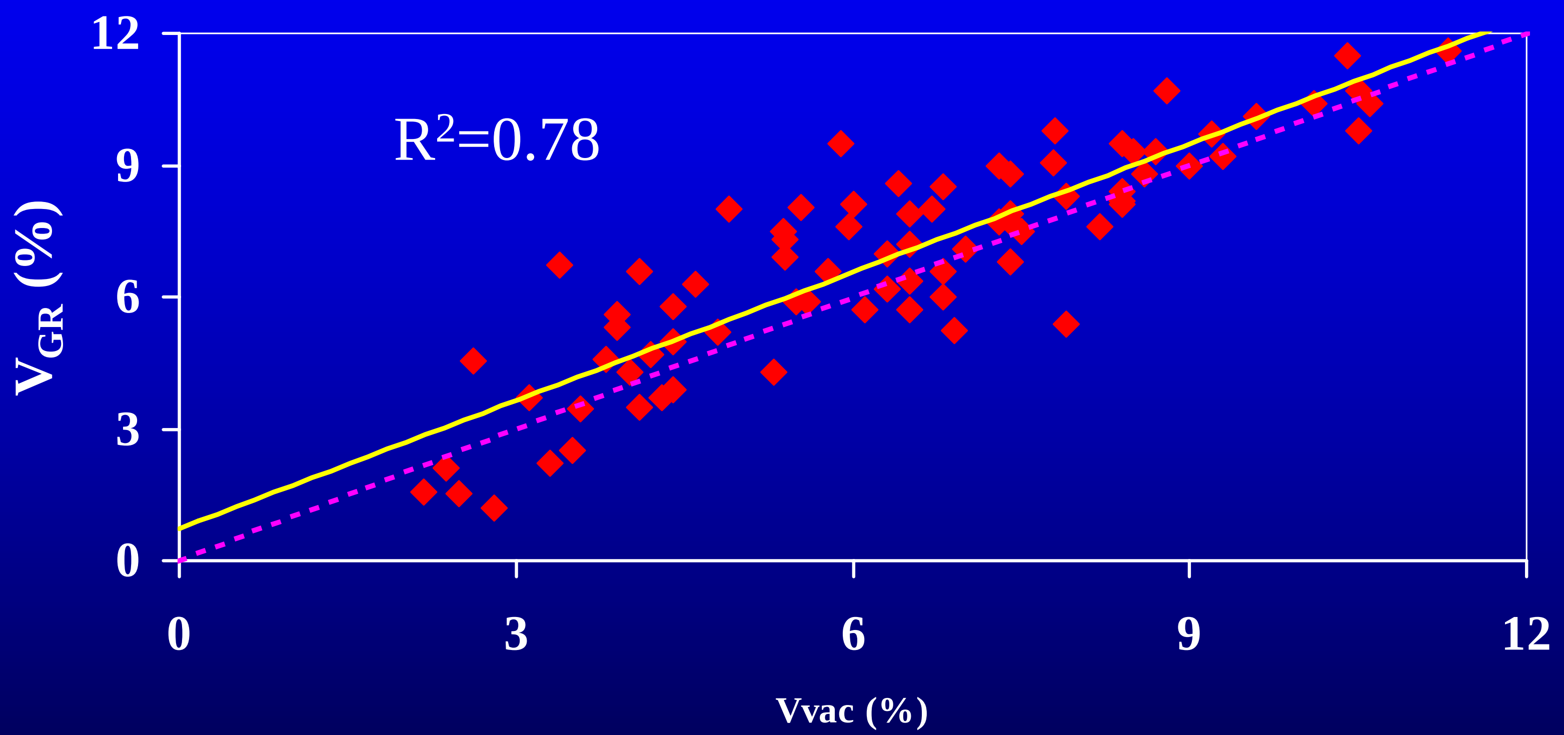

$$V_{VGR} = 1.1V_a + 0.9$$

# Vac. Sealing ($V_{VAC}$) vs. Eff. Porosity ($P_e$)



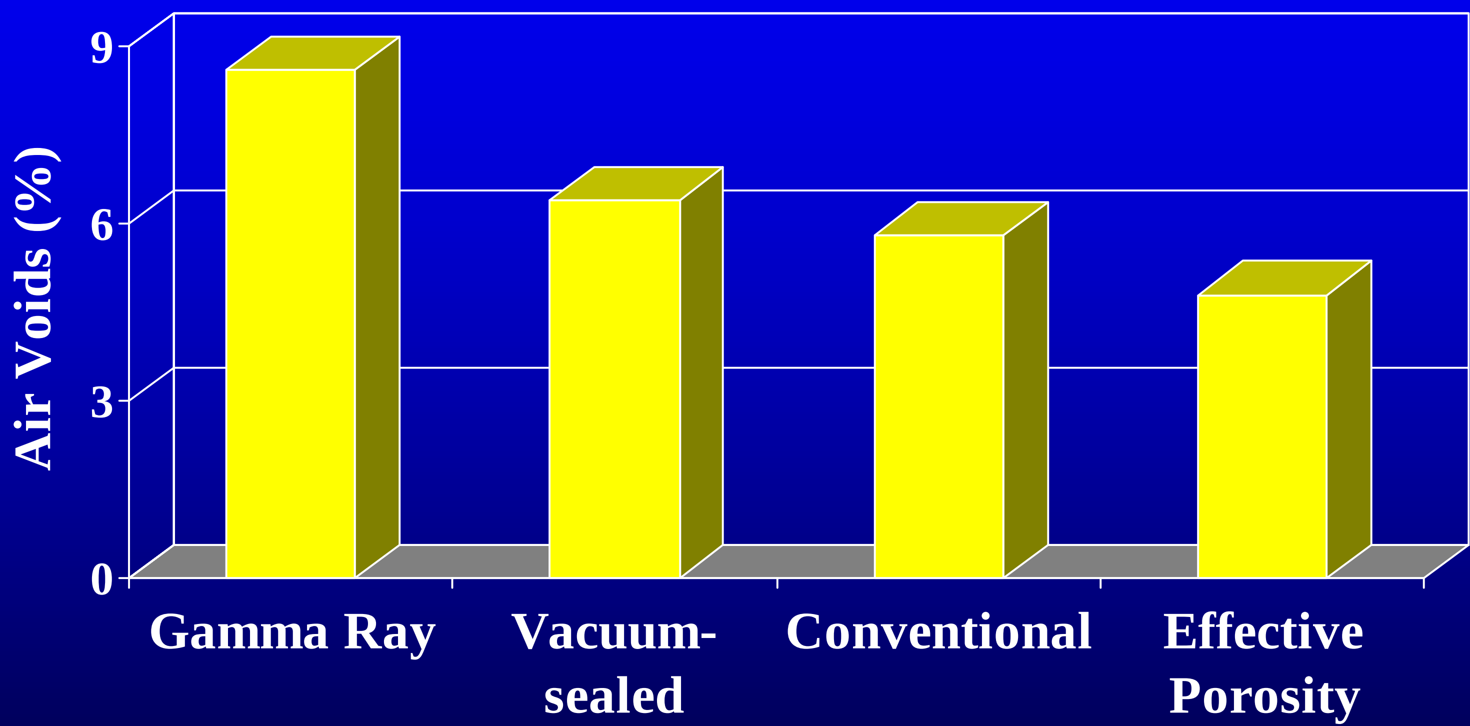

$$P_e = 1.1V_{VAC} - 1.0$$

# Vac. Sealing ($V_{VAC}$) vs. Gamma Ray $V_{GR}$

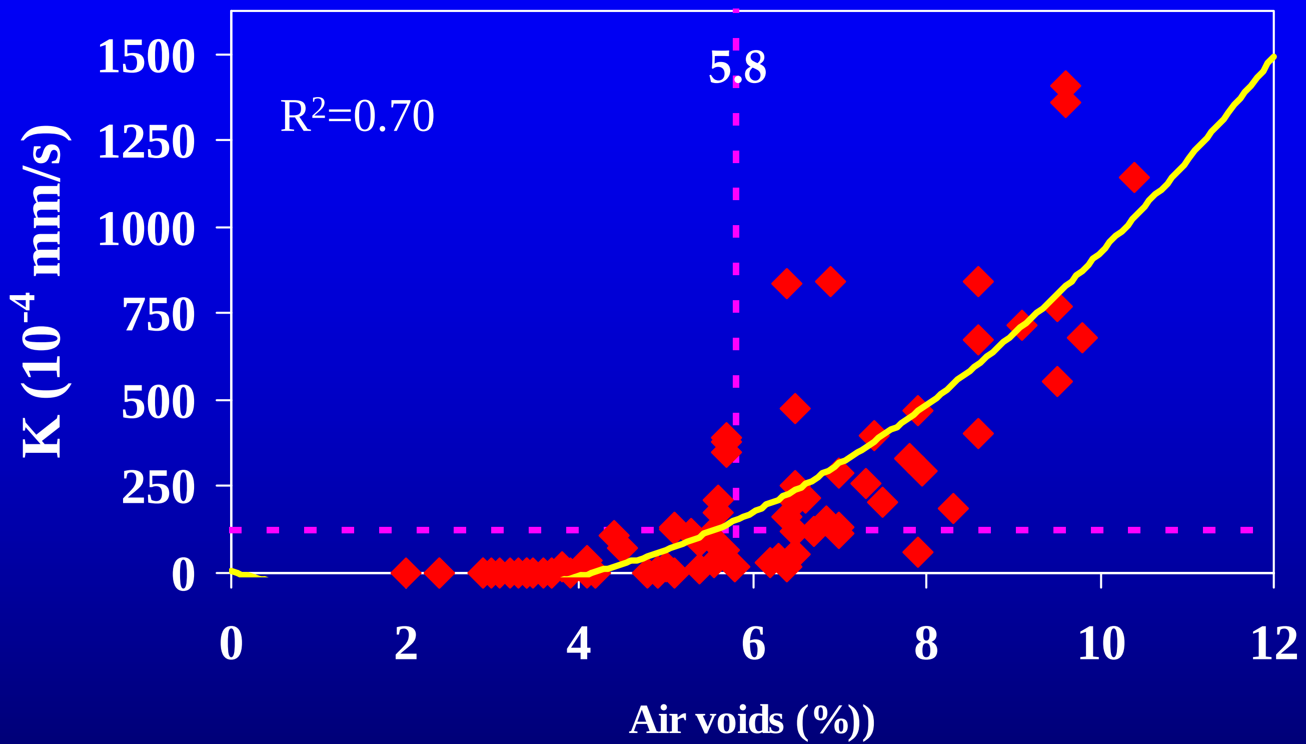



$$V_{GR} = 1.0V_{VAC} + 0.7$$

# Mean Air Voids from Different Test Procedures

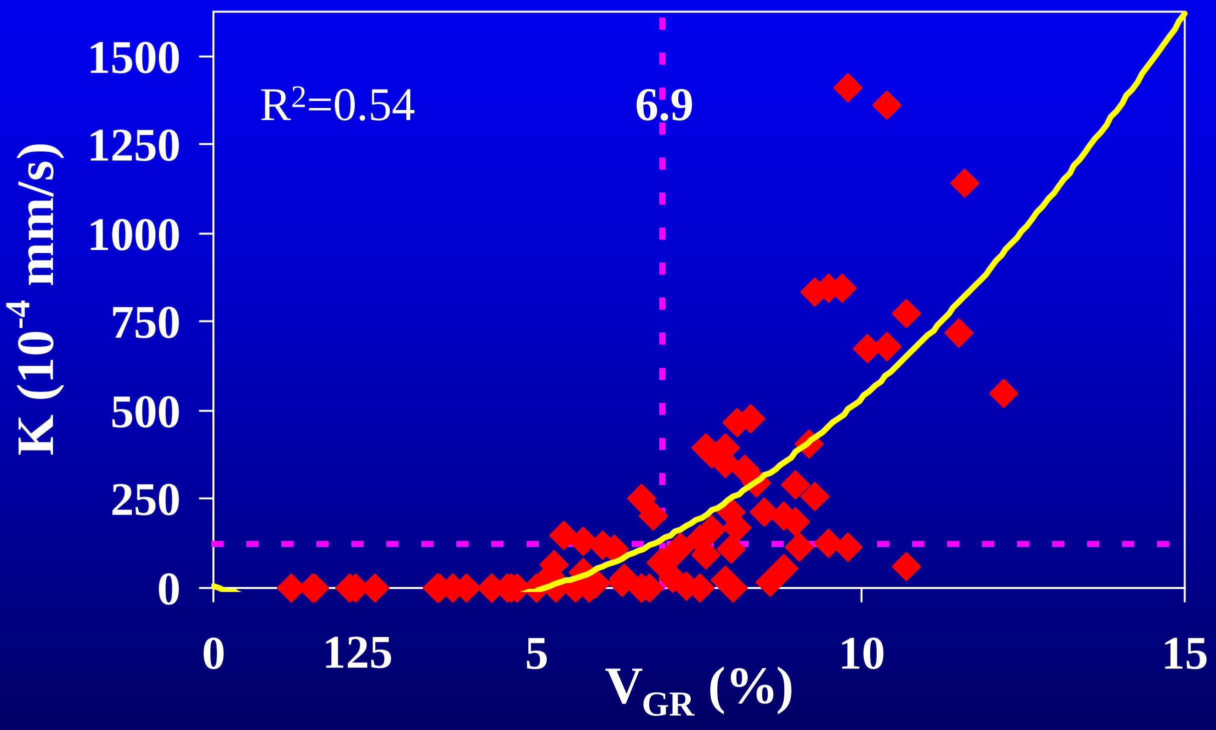


# Permeability vs. Conventional $V_a$



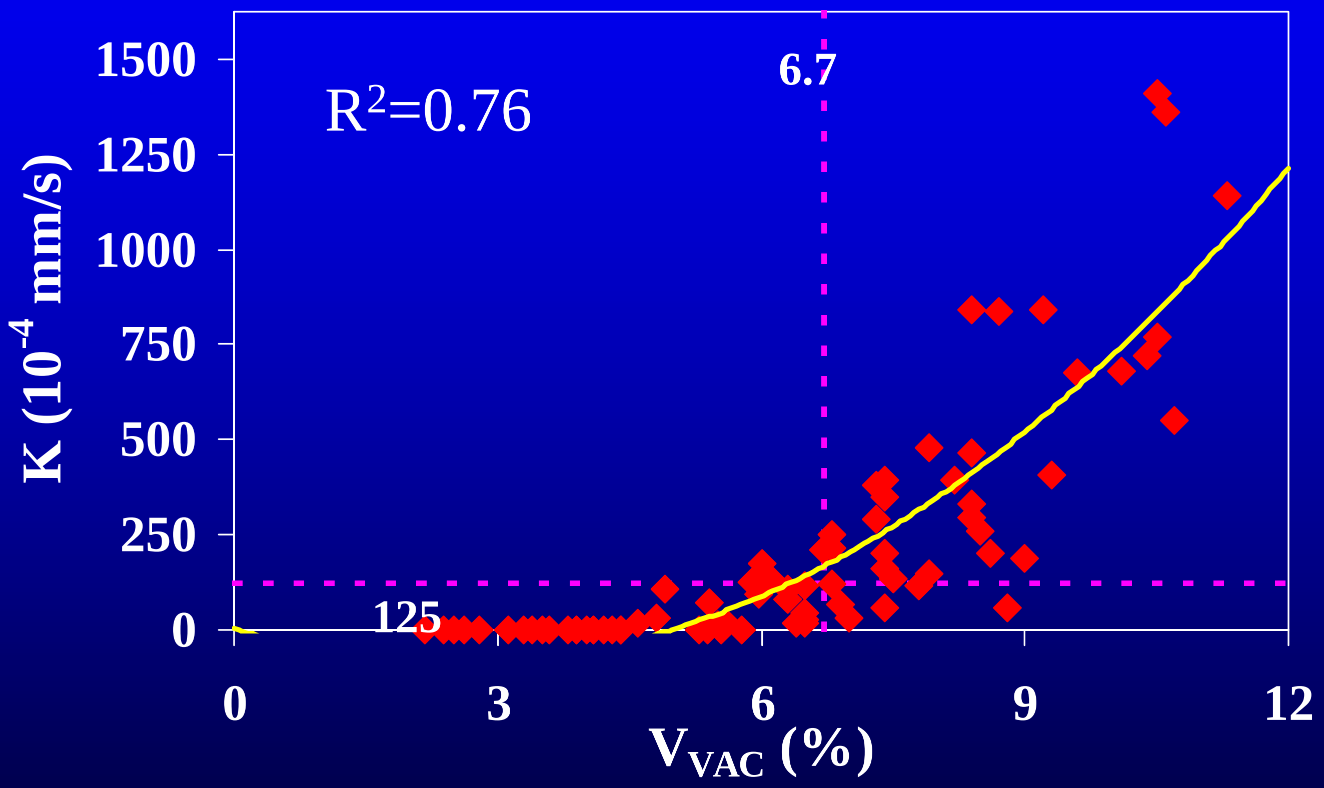

$$K = 10^{-4}\left(23.1V_a^2 - 160.6V_a + 279.6\right)$$

# Permeability vs. Gamma Ray ($V_{GR}$)



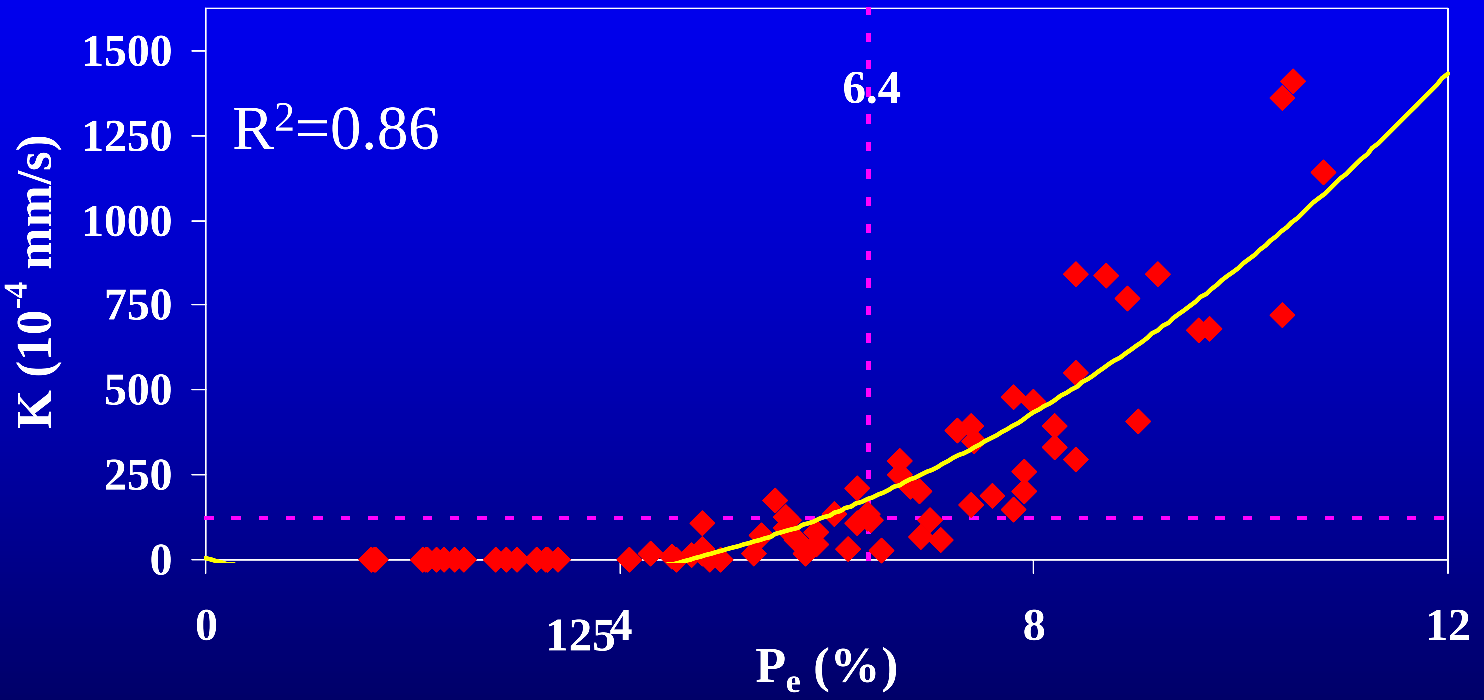

$$K = 10^{-4}\left(13.7V_{GR}^2 - 97.4V_{GR} + 143.2\right)$$

# Permeability vs. Vacuum-sealed ($V_{VAC}$)



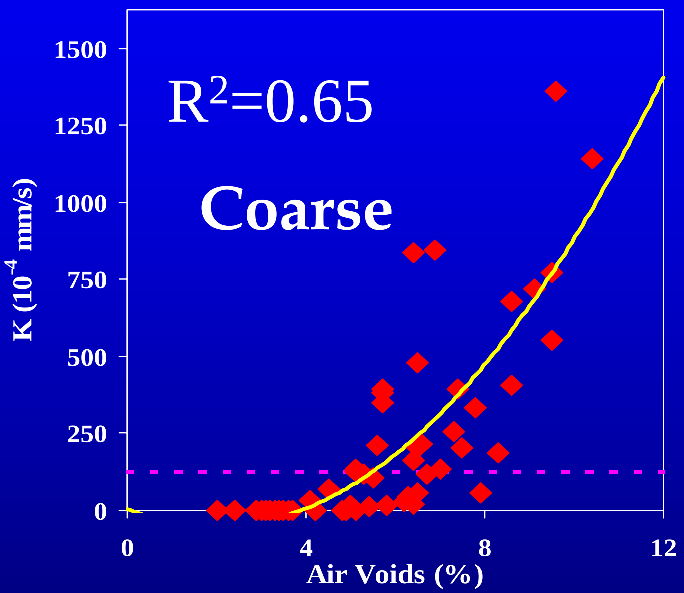

$$K = 10^{-4}\left(22.2V_{VAC}^{2} - 182.4V_{VAC} + 357.1\right)$$

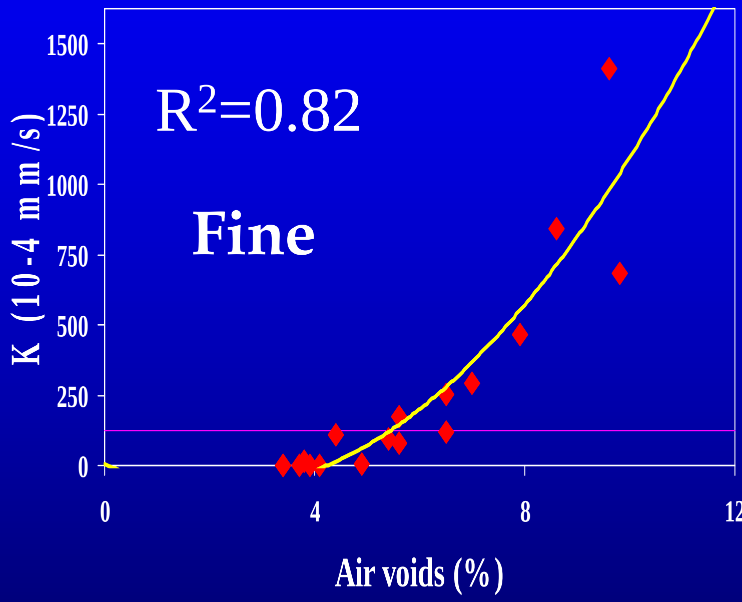
# Permeability vs. Effective Porosity ($P_e$)




$$K = 10^{-4}\left(23.8P_e^2 - 173.8P_e + 278.4\right)$$

# Effects of Gradation on Permeability and Air Voids: Coarse vs. fine

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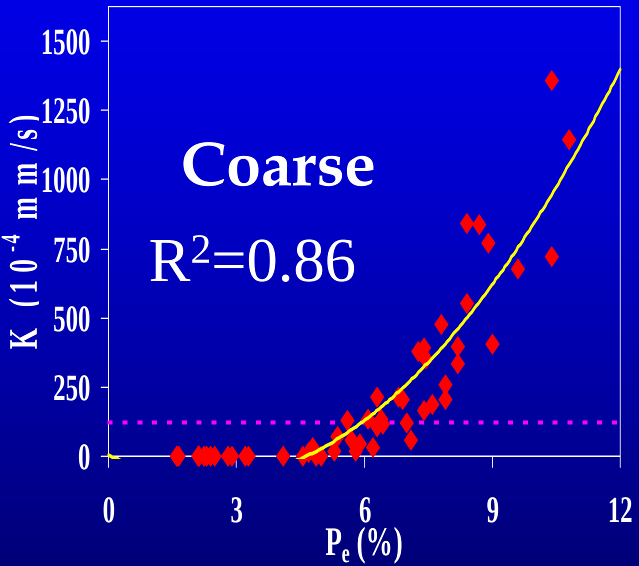
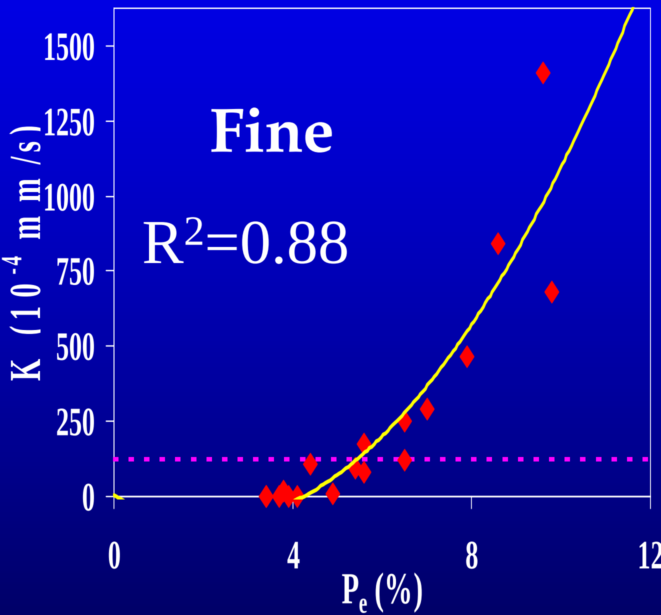
$$K = 10^{-4}\left(19.9V_a^2 - 125.9V_a + 201.8\right)$$

$$K = 10^{-4}\left(35.0V_a^2 - 299.8V_a + 646.1\right)$$

# Effects of Gradation on K and $P_e$: Coarse vs. fine

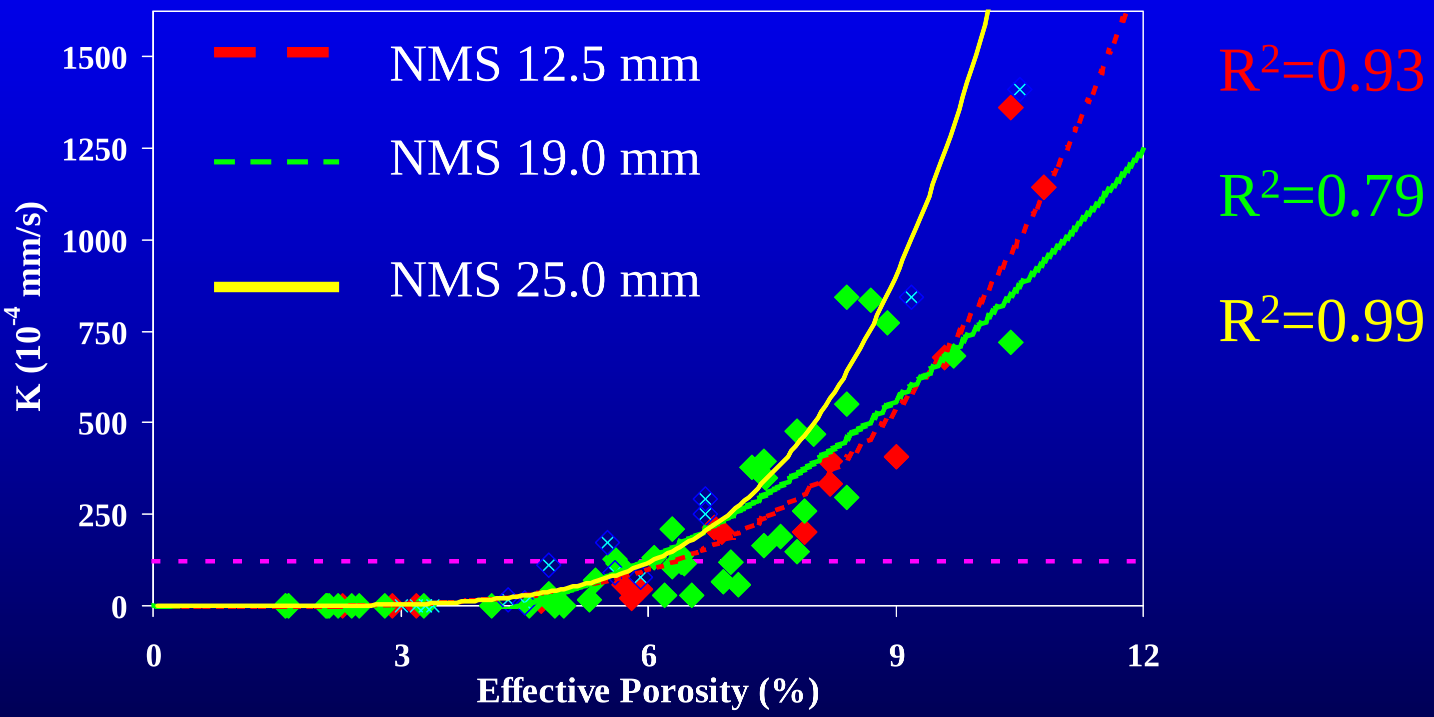


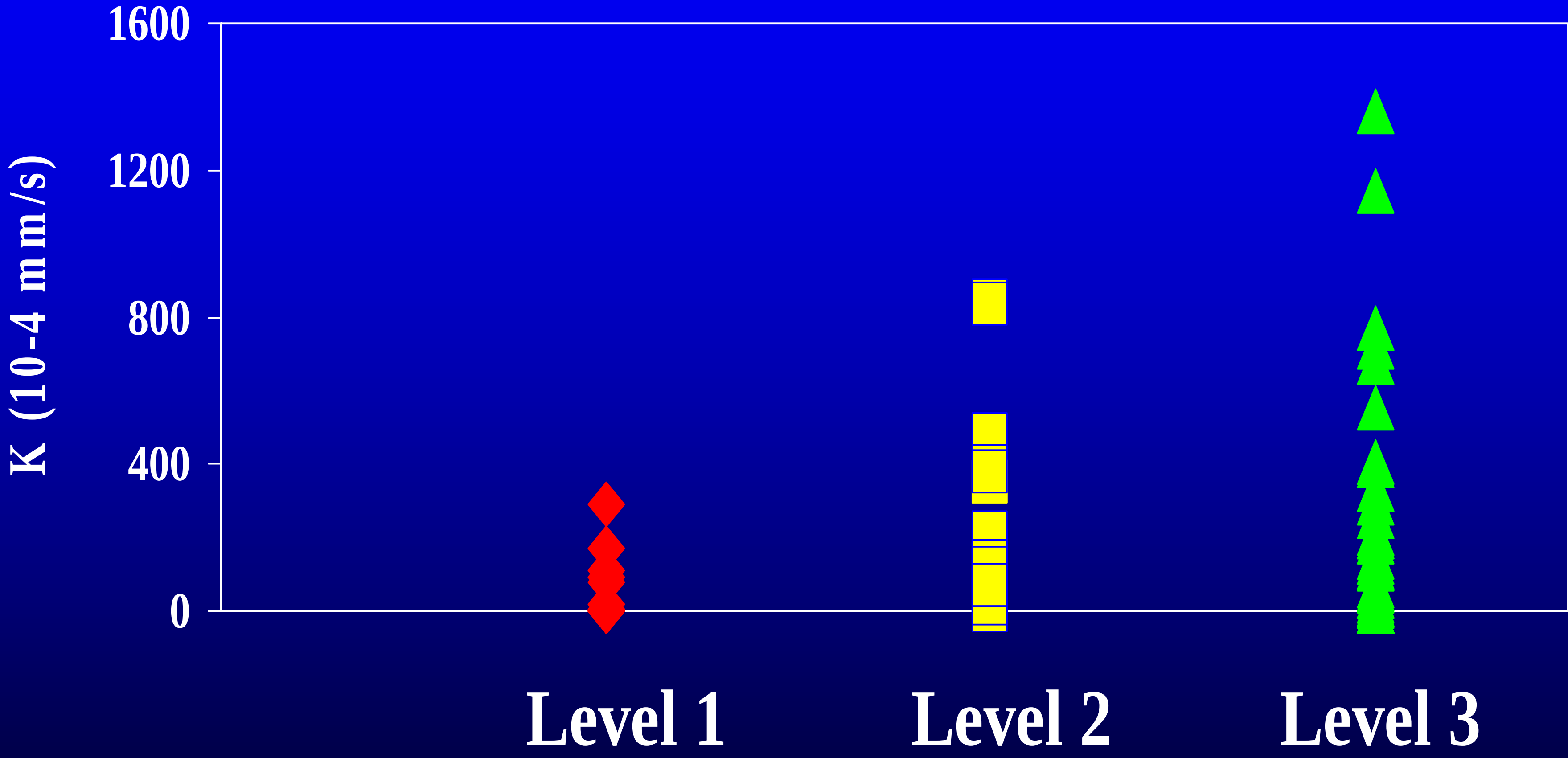

$$K = 10^{-4}\left(22.5P_e^2 - 158.4P_e + 236.3\right)$$

$$K = 10^{-4}\left(32.1P_e^2 - 283.4P_e + 617.3\right)$$

# Effects of NMS Permeability



# *Effects of Compaction Level on Permeability*



# *Development of Prediction Models*

- Multiple Regression Analysis
- Influencing Factor
  – Air voids,
  – effective porosity,
  – aggregate gradation characteristics
- Parametric analysis
  – Suitable variables

# Permeability Prediction Models

$$K_{p_e} = 10^{-4}\left[24.9(P_e^2) - 180.8P_e + 67.4P_{0.075} - 31.9P_{0.3} + 55.7P_{0.6} - 36.3P_{2.36} + 4.9P_{12.50}\right]$$

$R^2$=0.87
RMSE=118 x$10^{-4}$

$$K_{vac} = 10^{-4}\left[23.5(V_{VAC}^2) - 186.8V_{VAC} + 108.6P_{0.075} - 45.0P_{0.3} + 61.3P_{0.6} - 40.2P_{2.36} + 4.9P_{12.50}\right]$$

$R^2$=0.79
RMSE=149 x$10^{-4}$

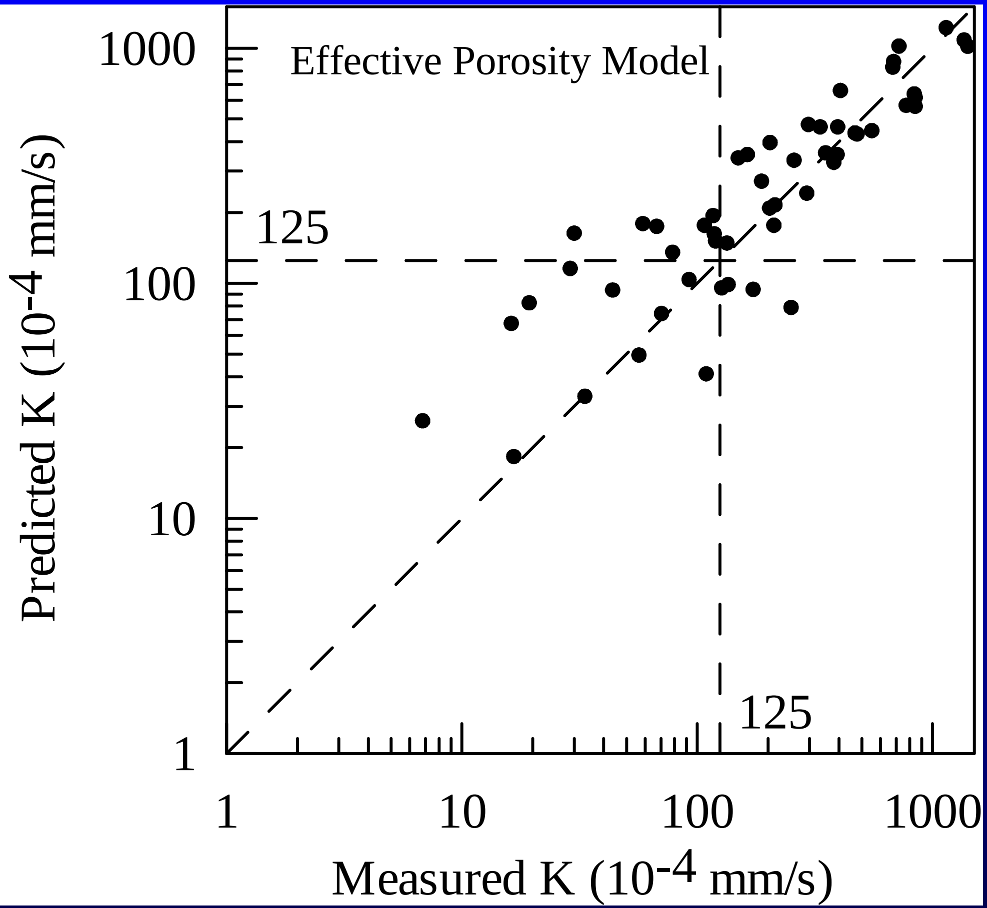
$$K_{v_a} = 10^{-4}\left[23.8(V_a^2) - 147.8V_a + 114.5P_{0.075} - 49.1P_{0.3} + 65.5P_{0.6} - 48.7P_{2.36} + 5.4P_{12.50}\right]$$

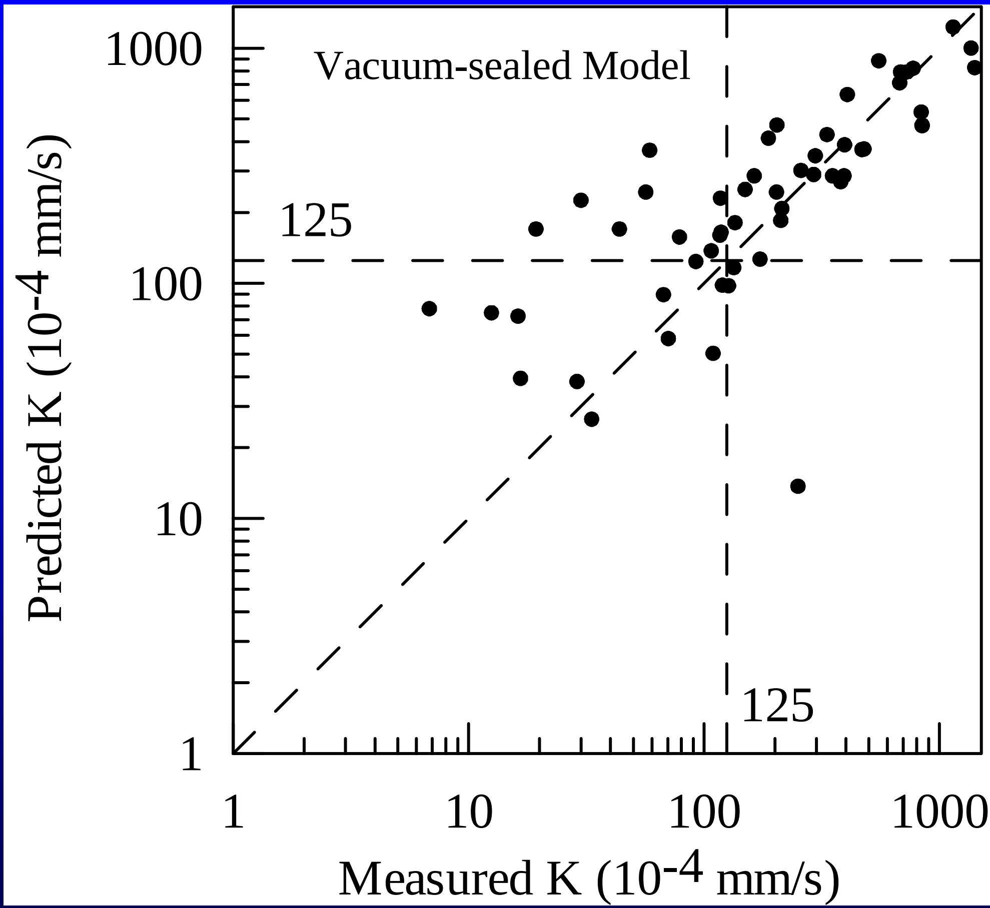
$R^2$=0.73
RMSE=171 x$10^{-4}$

$$K_{GR} = 10^{-4}\left[15.9(V_{GR}^2) - 130.5V_{GR} + 51.1P_{0.075}\right]$$

$R^2$=0.57
RMSE=209 x$10^{-4}$

# Predictions: Effective porosity and Vacuum-sealed Models

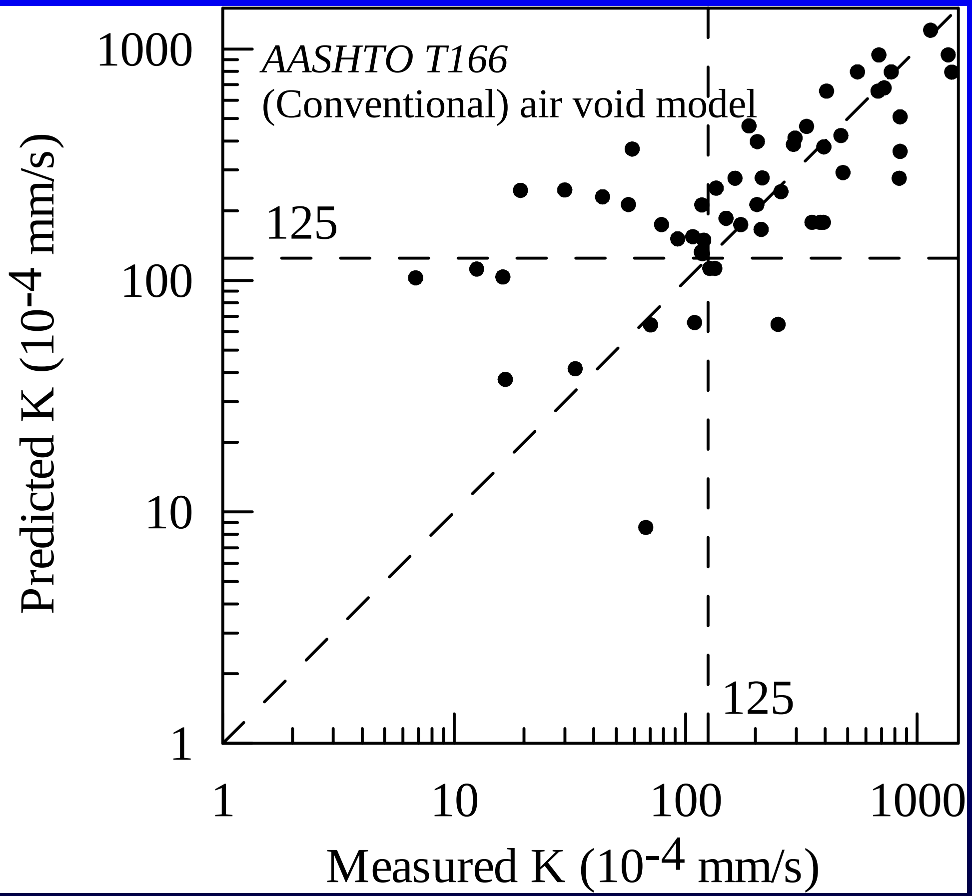


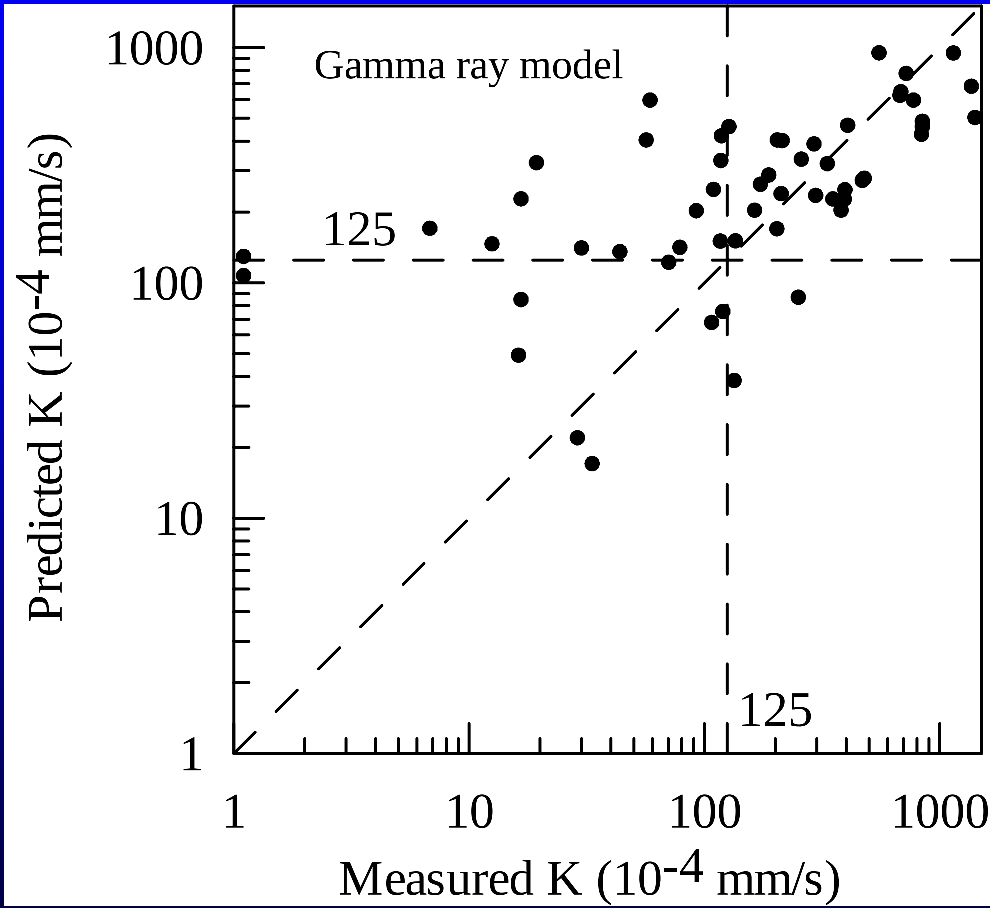




$R^2$=0.87,
RMSE=0.0118

$R^2$=0.79,
RMSE=0.0149

# Predictions: Conventional and Gammaray Models




**$R^2$=0.73, RMSE=0.0171**

**$R^2$=0.57, RMSE=0.0209**

# *Summary and Conclusion*

- Falling head permeability tests were conducted
- Gamma ray method provided higher air voids values than the other methods (vacuum sealing and *AASHTO T166).*
- Good correlation was observed between air voids estimated from Vacuum sealing method and AASHTO T166
- The air voids values at which $K > 125 \times 10^{-4}$ mm/s varied with the air void measurement method
  - 6.9 Gamma Ray
  - 6.7 Vacuum sealing
  - 5.8 AASHTO T166

# ***Summary and Conclusion***

- **Fine-graded mixtures showed better correlations between conventional air voids and K than coarse-graded mixtures**
- **Similar correlations were observed for both fine- and coarse-graded mixtures between Pe and K**
- **Permeability increased with an increase in the mixture nominal maximum aggregate size**
- **No correlation was found between the compaction levels**
- ***<u>Preliminary</u>* models were developed to predict the permeability**
  - **based on the air voids, effective porosity, and aggregate gradation characteristics**
- **A good agreement was observed between the predicted and the measured permeability values from the effective porosity model**

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