Factors Influencing the Permeability of Hot-Mix Asphalt Mixtures

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Louisiana Asphalt Technology Conference
February 23-24, 2005
Shreveport, Louisiana

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

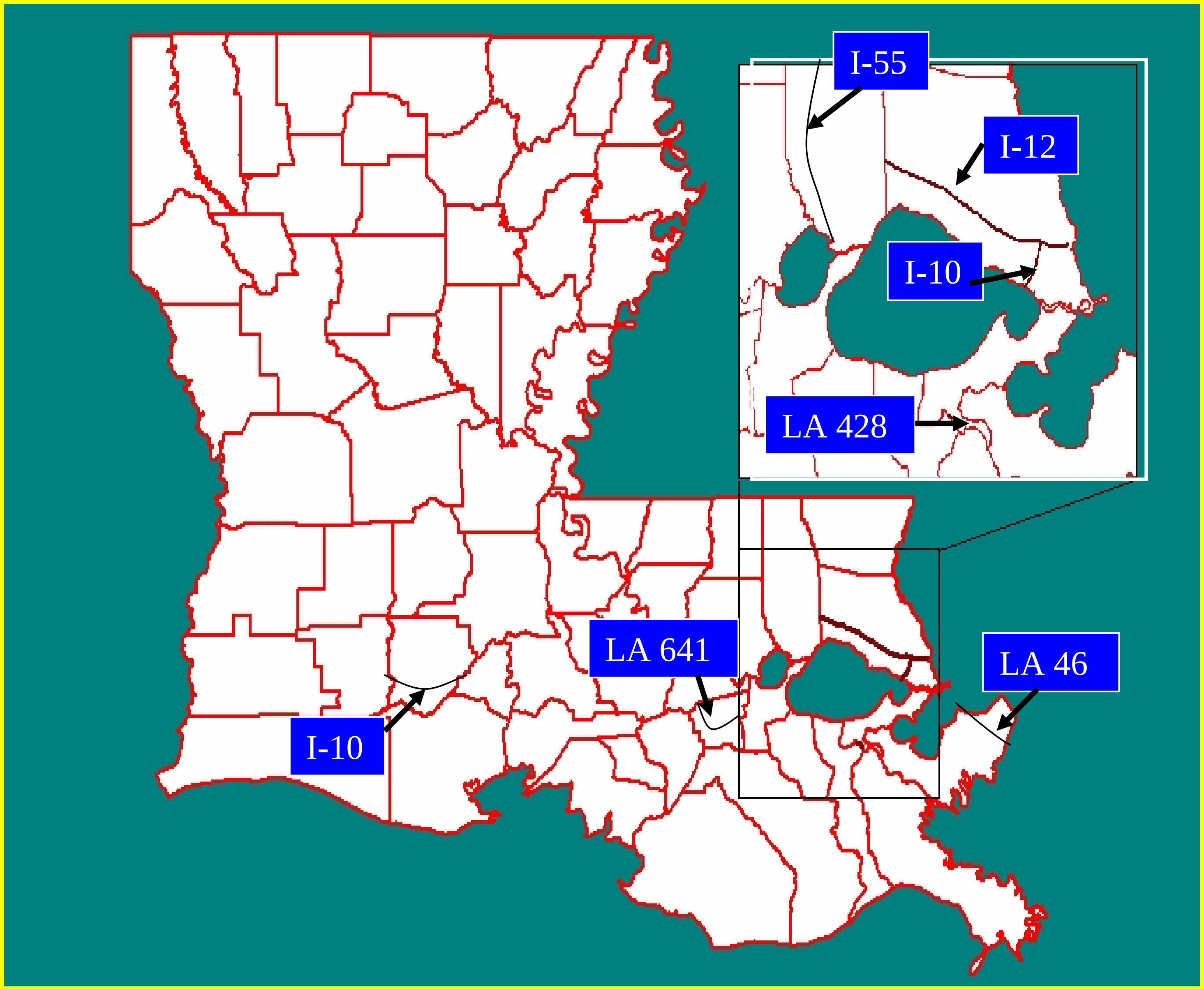
Air voids vs Permeability

- 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)

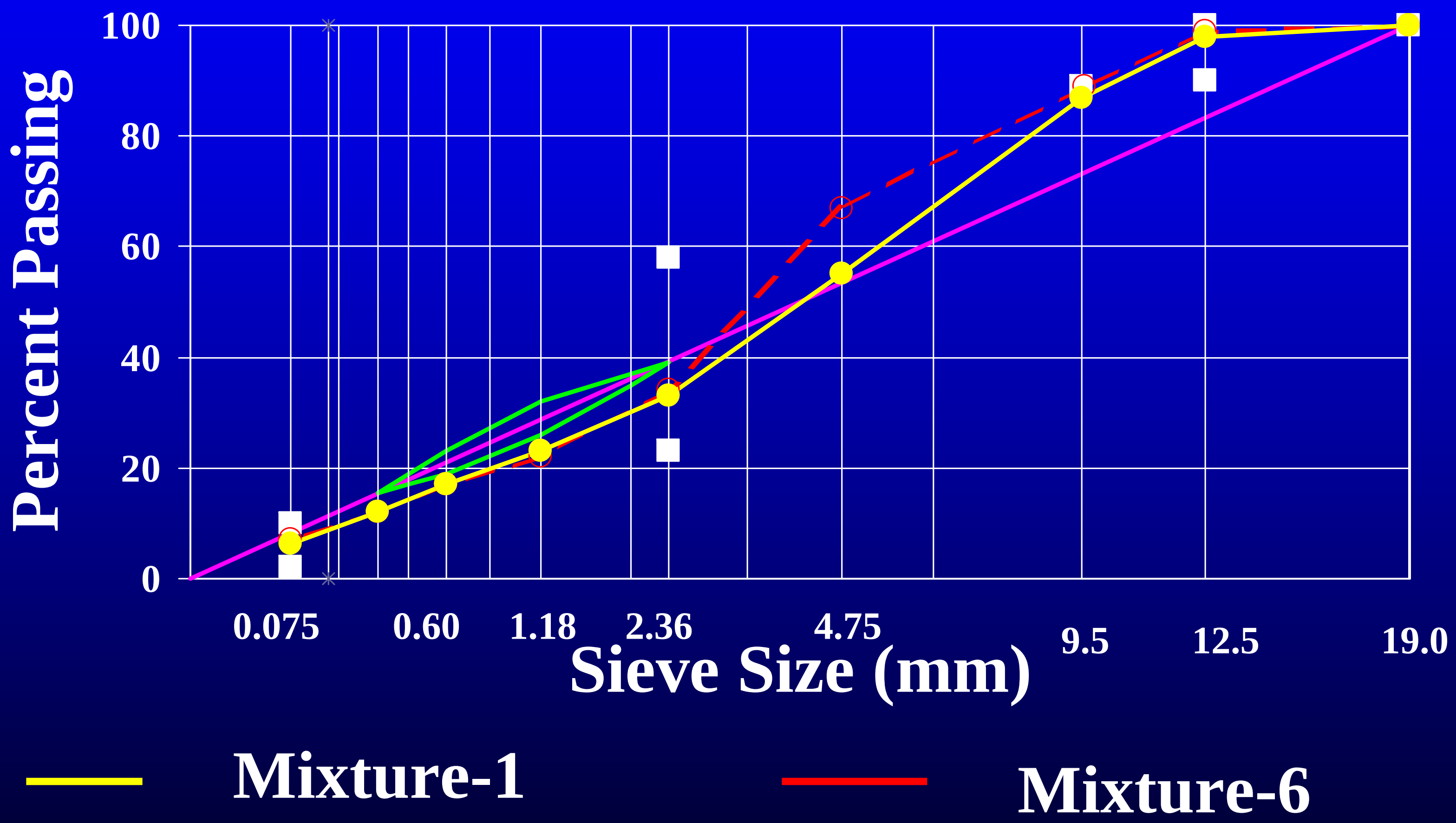
SCOPE



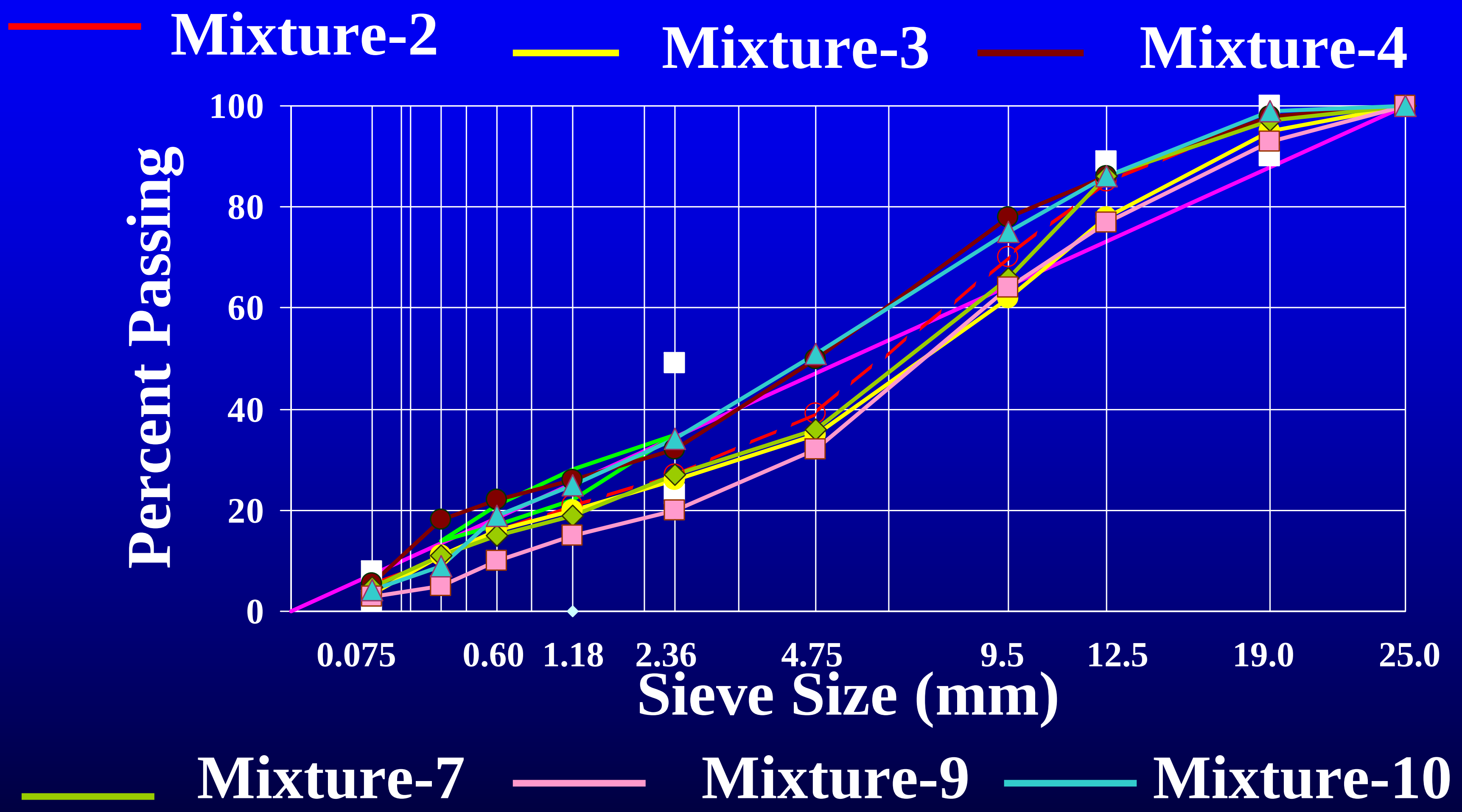
Scope

- 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

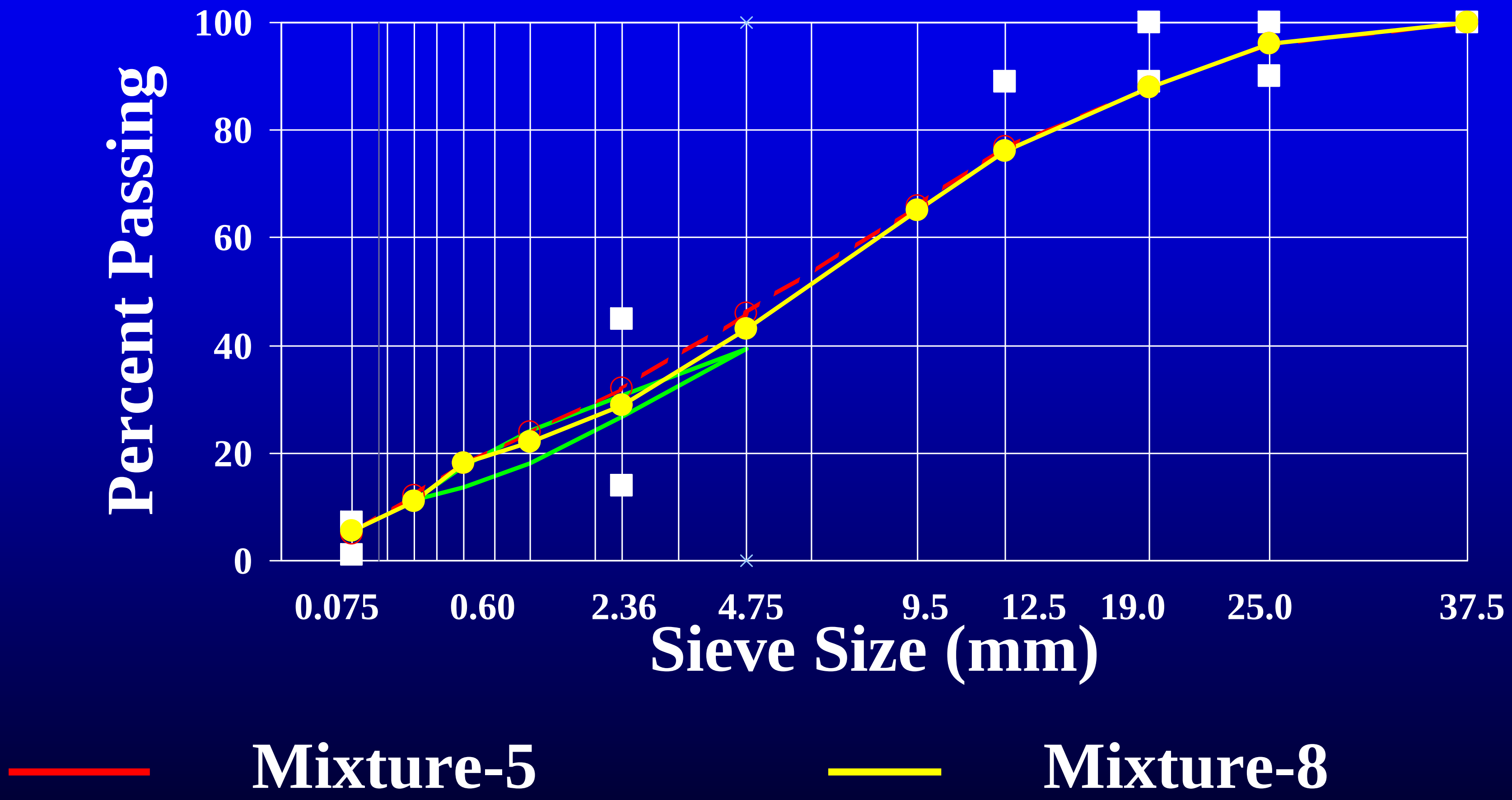
Gradation Chart for 12.5 mm



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

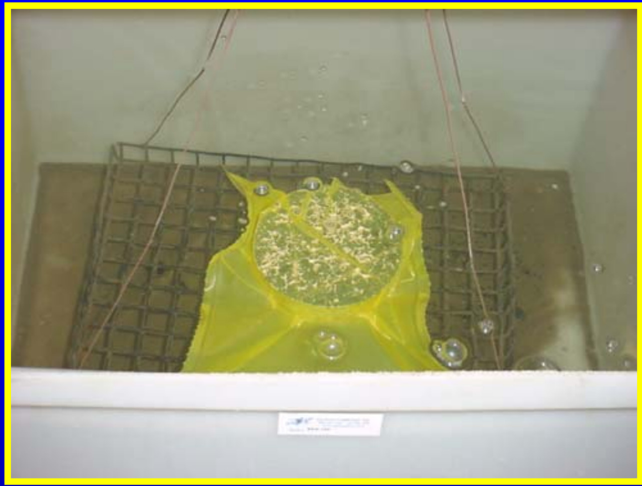
Submerged
Weight

Gamma Ray Method (Air Void)

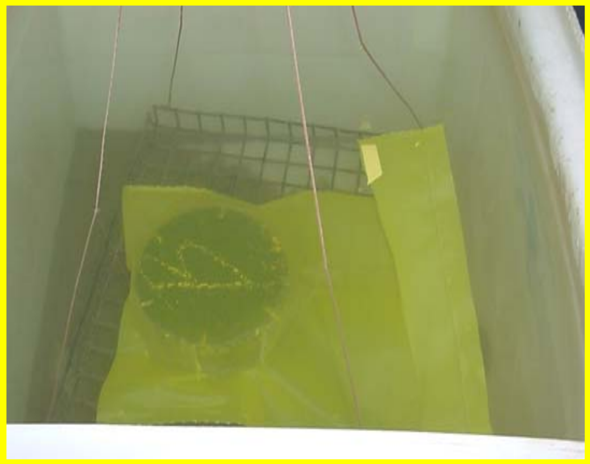
Effective Porosity Procedure

Dry weight

Vacuum sealing



Submerged weight



Submerged sample weight with the open bag

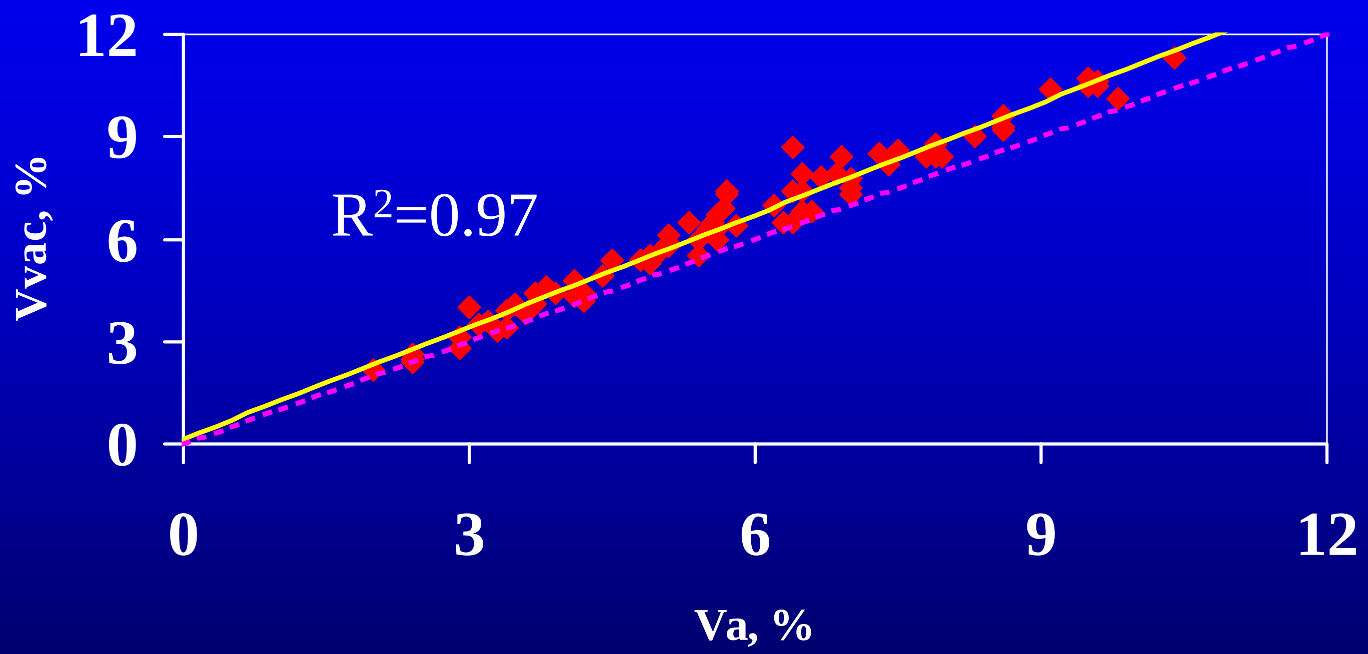
Laboratory Permeability

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

Permeability Procedure

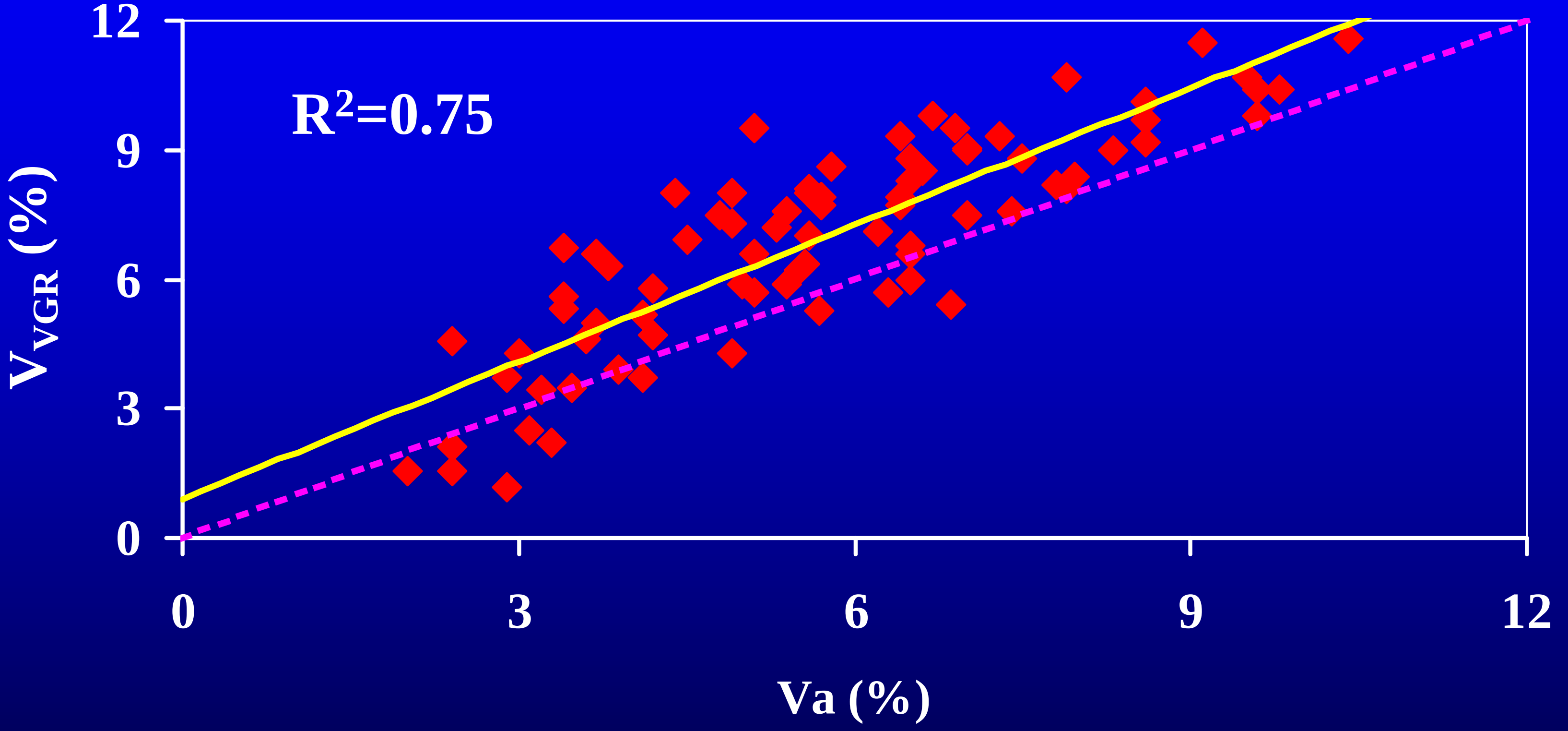
Discussion of Results

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



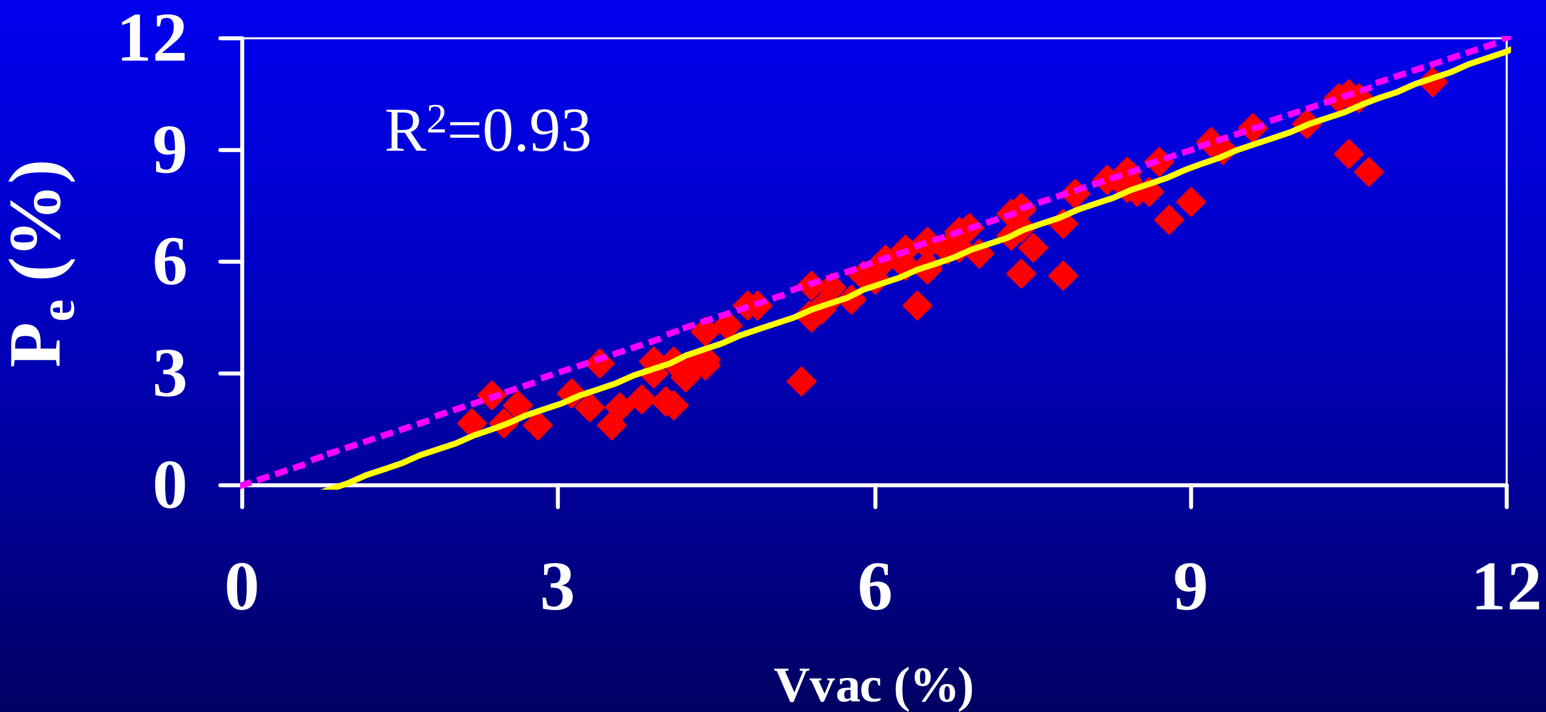
$$V_{VAC} = 1.1V_a + 0.2$$

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



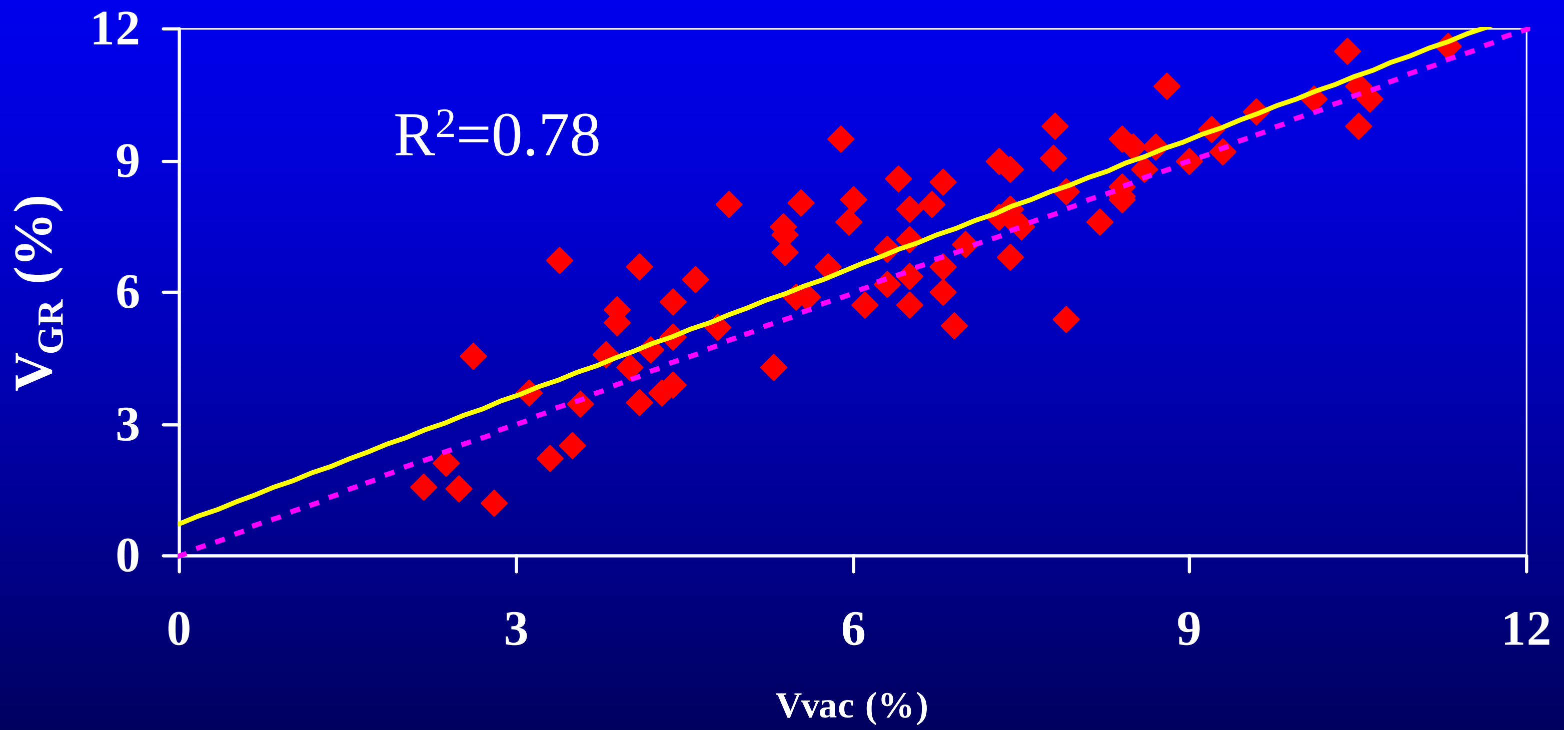
$$V_{VGR} = 1.1V_a + 0.9$$

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



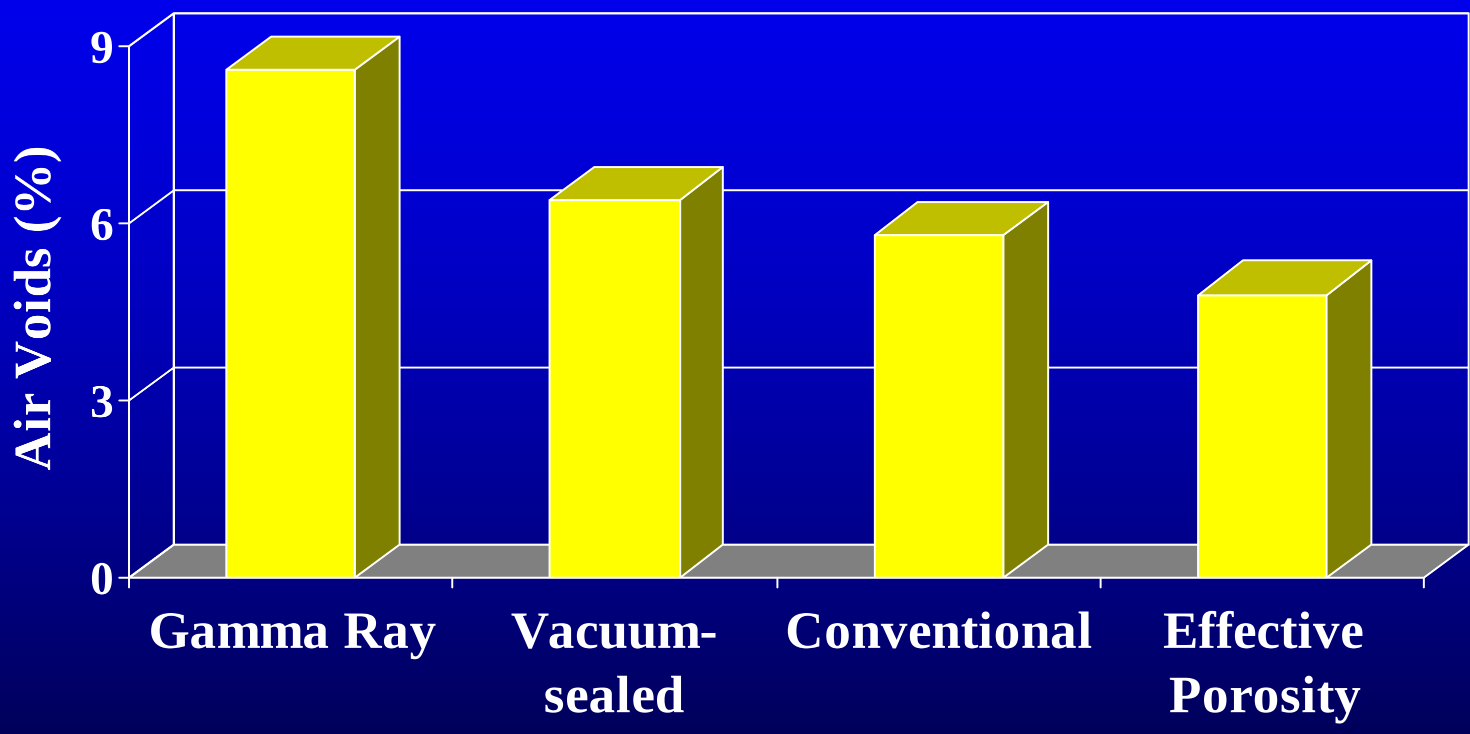
$$P_e = 1.1V_{VAC} - 1.0$$

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

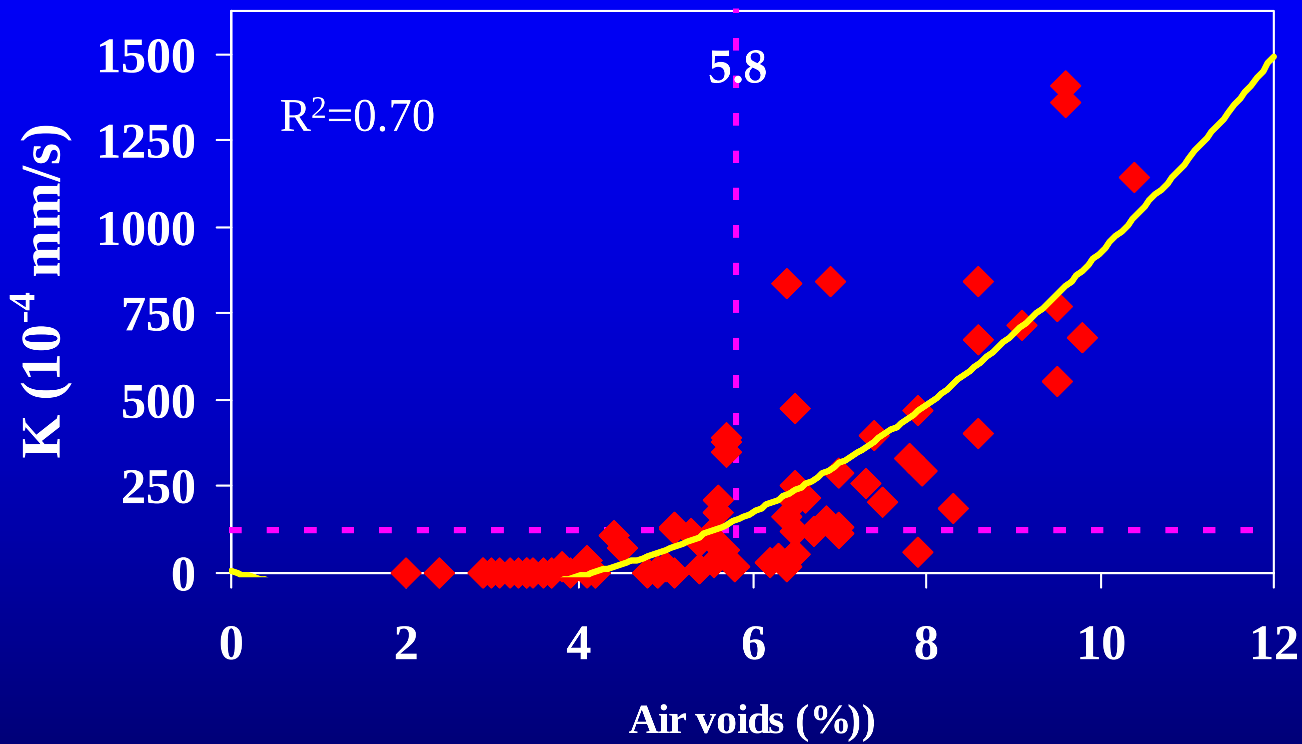


$$V_{GR} = 1.0V_{VAC} + 0.7$$

Mean Air Voids from Different Test Procedures

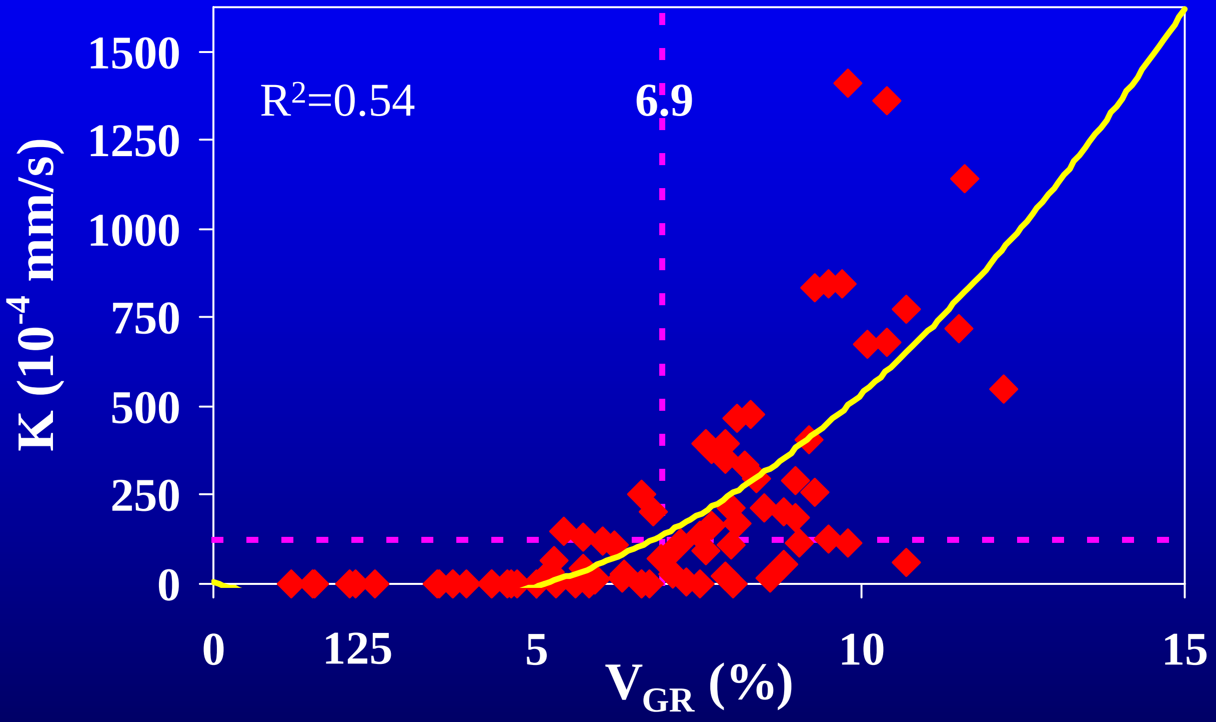


Permeability vs. Conventional V_a



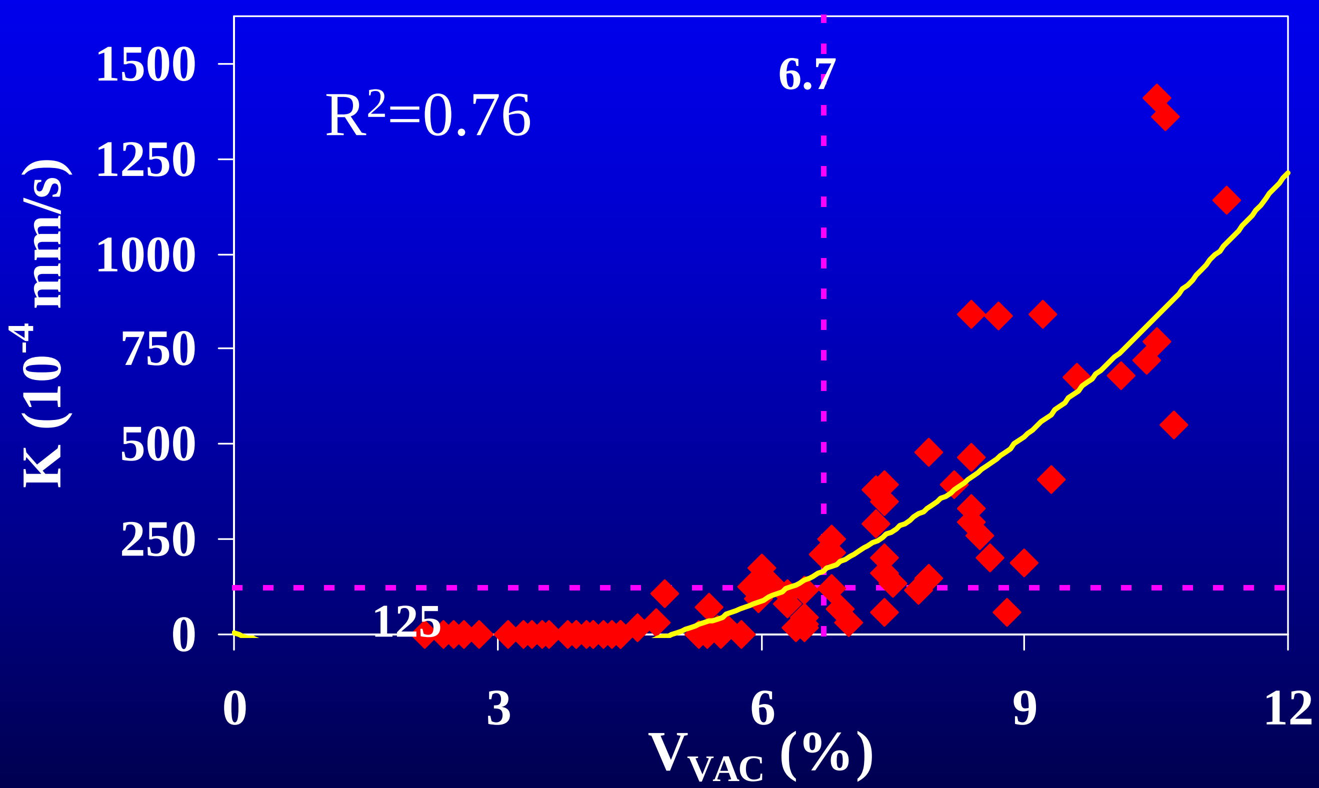
$$K = 10^{-4}\left(23.1V_a^2 - 160.6V_a + 279.6\right)$$

Permeability vs. Gamma Ray (V_{GR})



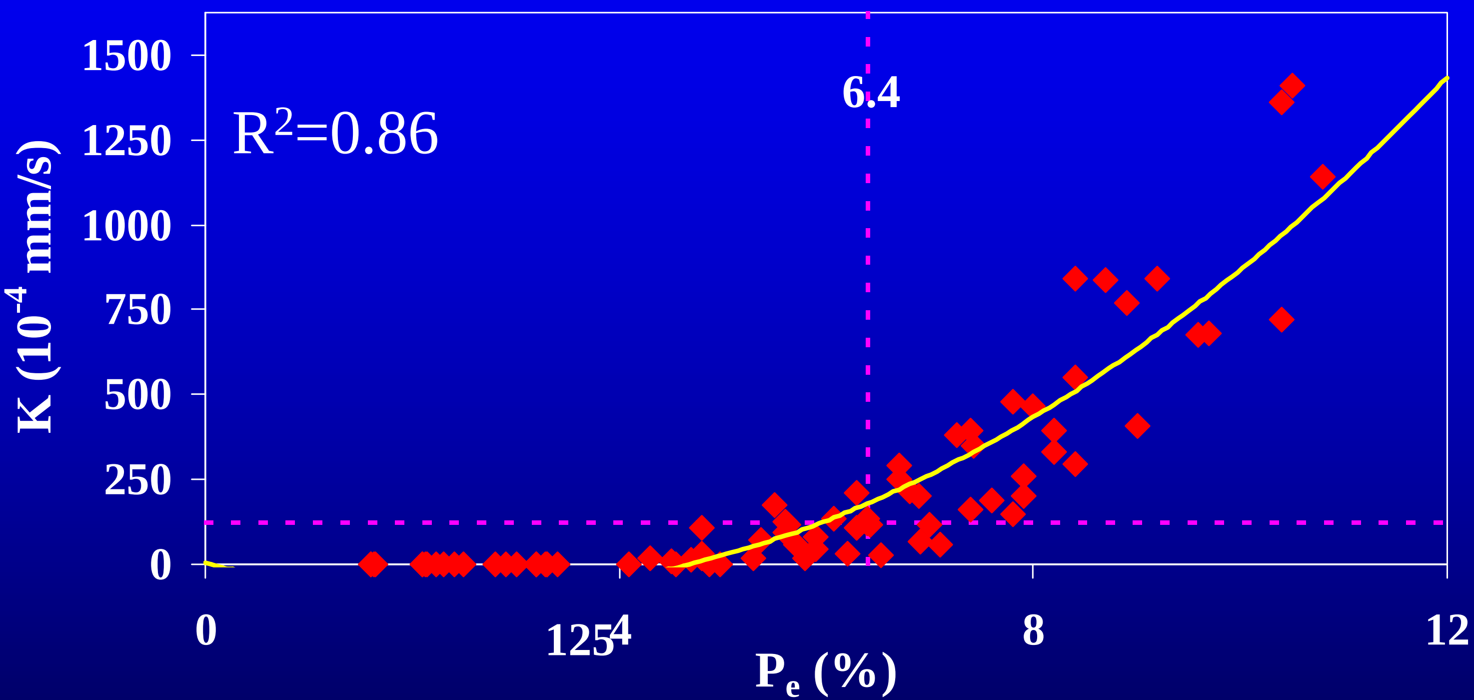
$$K = 10^{-4}\left(13.7V_{GR}^2 - 97.4V_{GR} + 143.2\right)$$

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



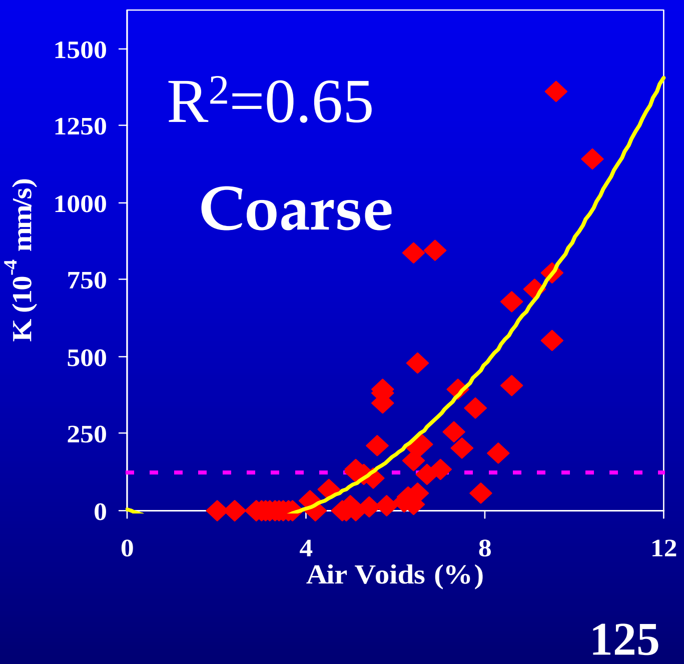
$$K = 10^{-4}\left(22.2V_{VAC}^{2} - 182.4V_{VAC} + 357.1\right)$$

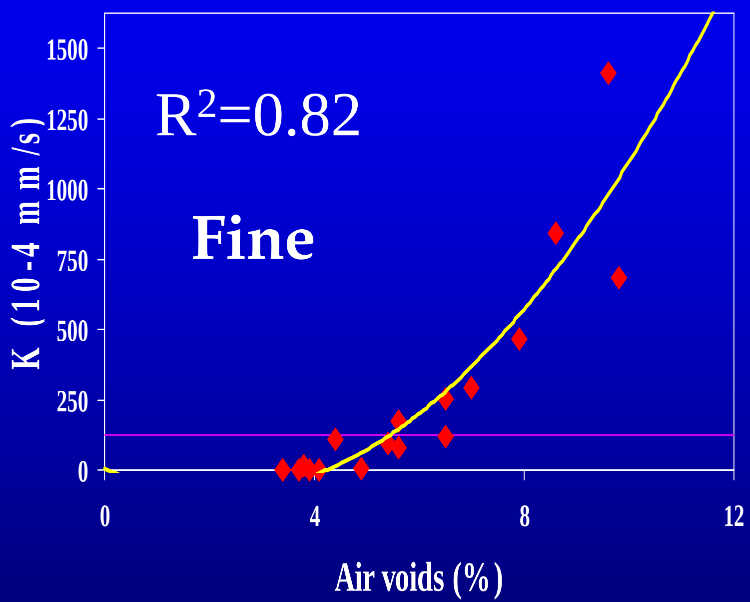
Permeability vs. Effective Porosity (P_e)



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

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

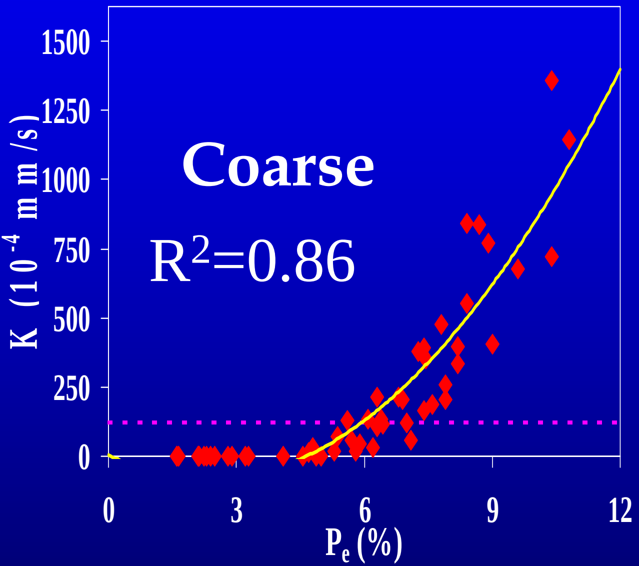


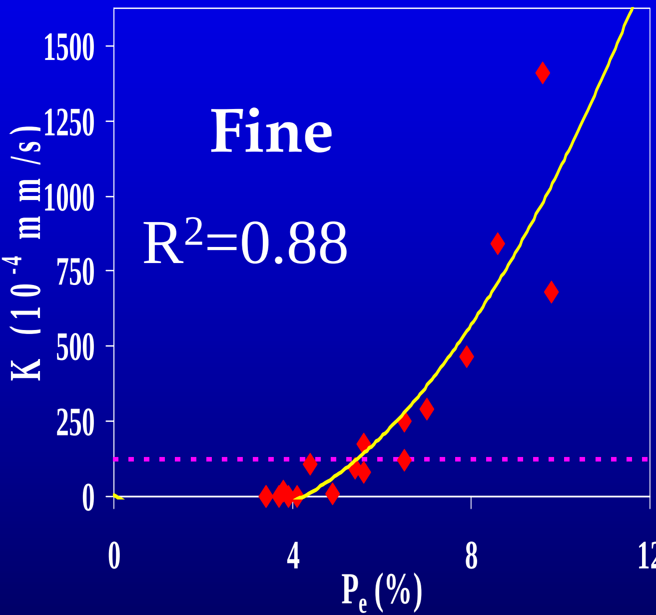


$$K = 10^{-4}\left(19.9V_a^2 - 125.9V_a + 201.8\right)$$

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

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

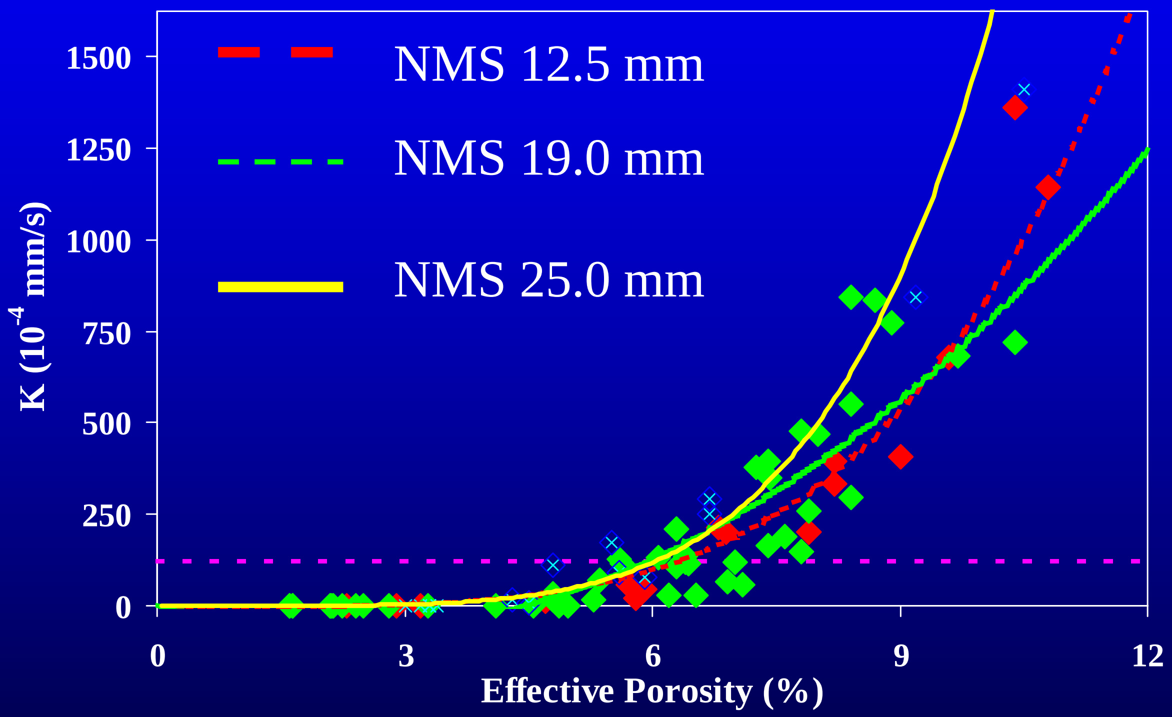




$$K = 10^{-4}\left(22.5P_e^2 - 158.4P_e + 236.3\right)$$

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

Effects of NMS Permeability

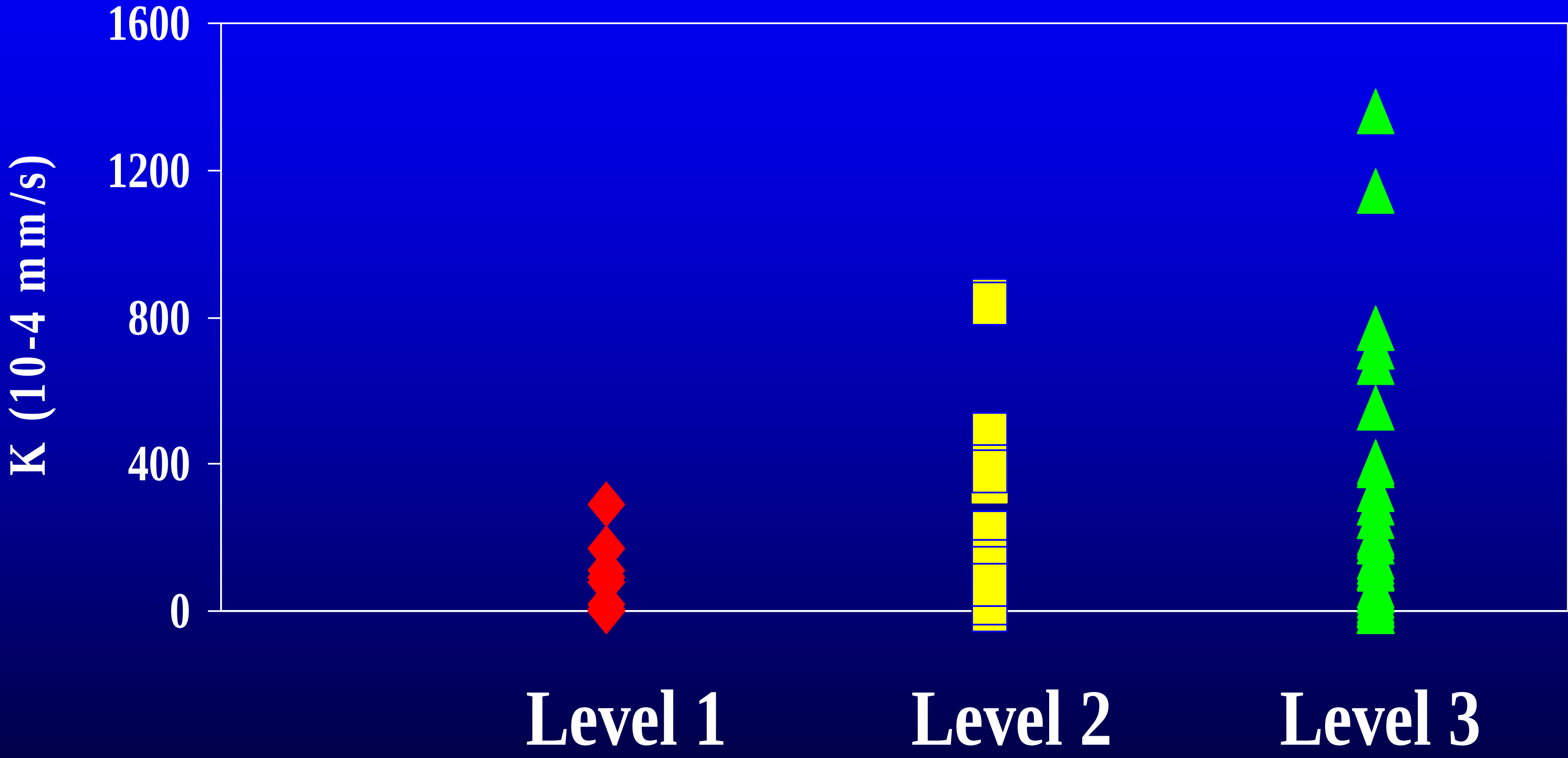


R^2=0.93

R^2=0.79

R^2=0.99

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 x10^{-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 x10^{-4}

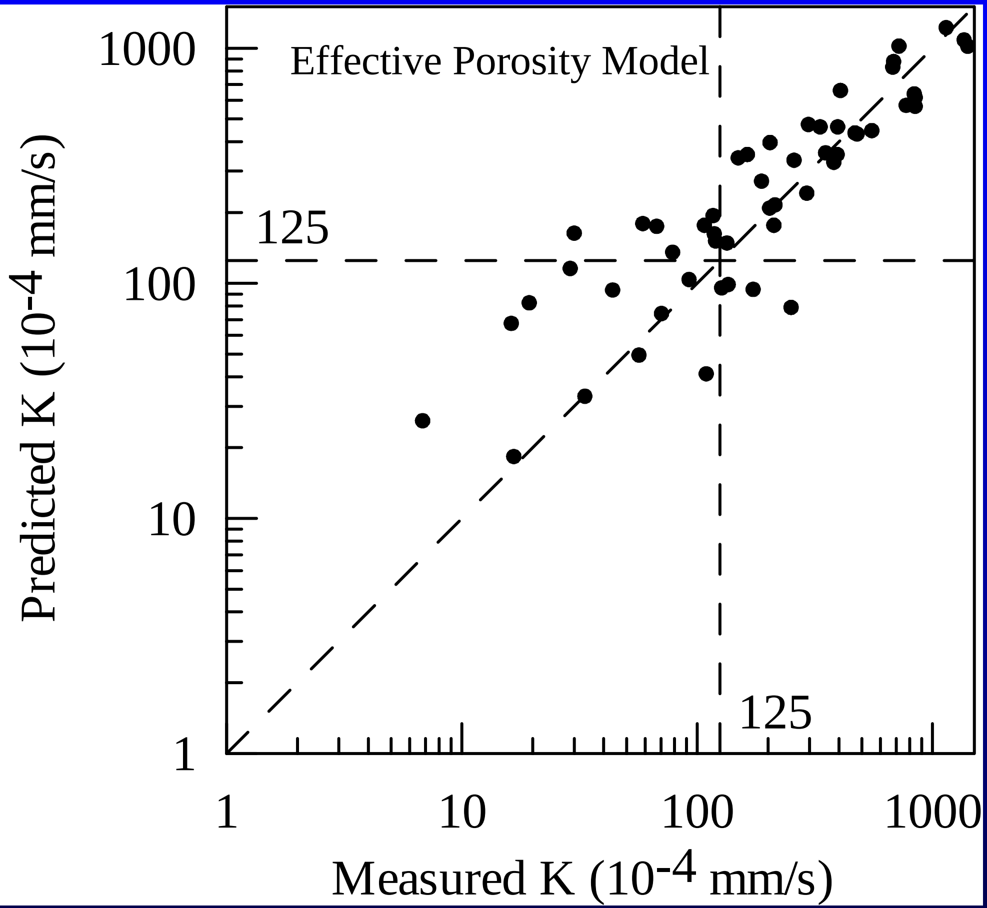
$$K_{v_a} = 10^{-4}\left[23.8(V_a^2) - 147.8V_a + 114.5P_{0.075} - 49.1P_{0.3} + 65.5P_{0.6} - 48.7P_{2.36} + 5.4P_{12.50}\right]$$

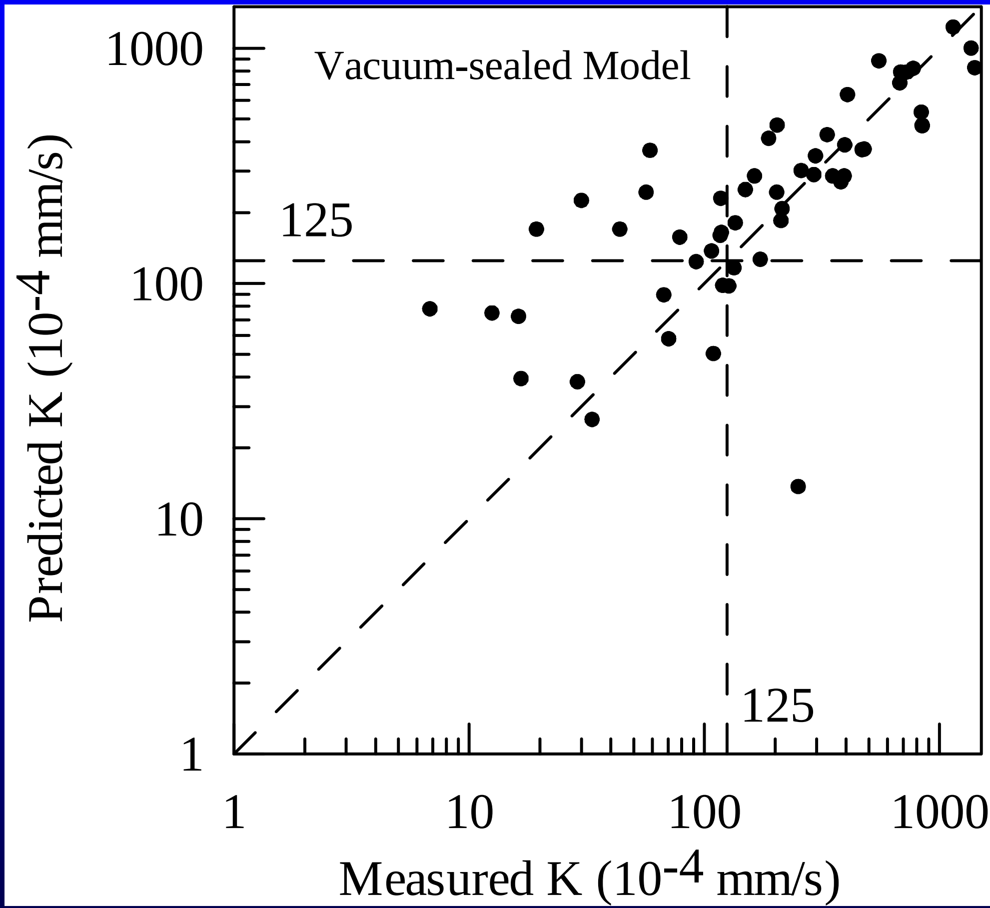
R^2=0.73
RMSE=171 x10^{-4}

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

R^2=0.57
RMSE=209 x10^{-4}

Predictions: Effective porosity and Vacuum-sealed Models

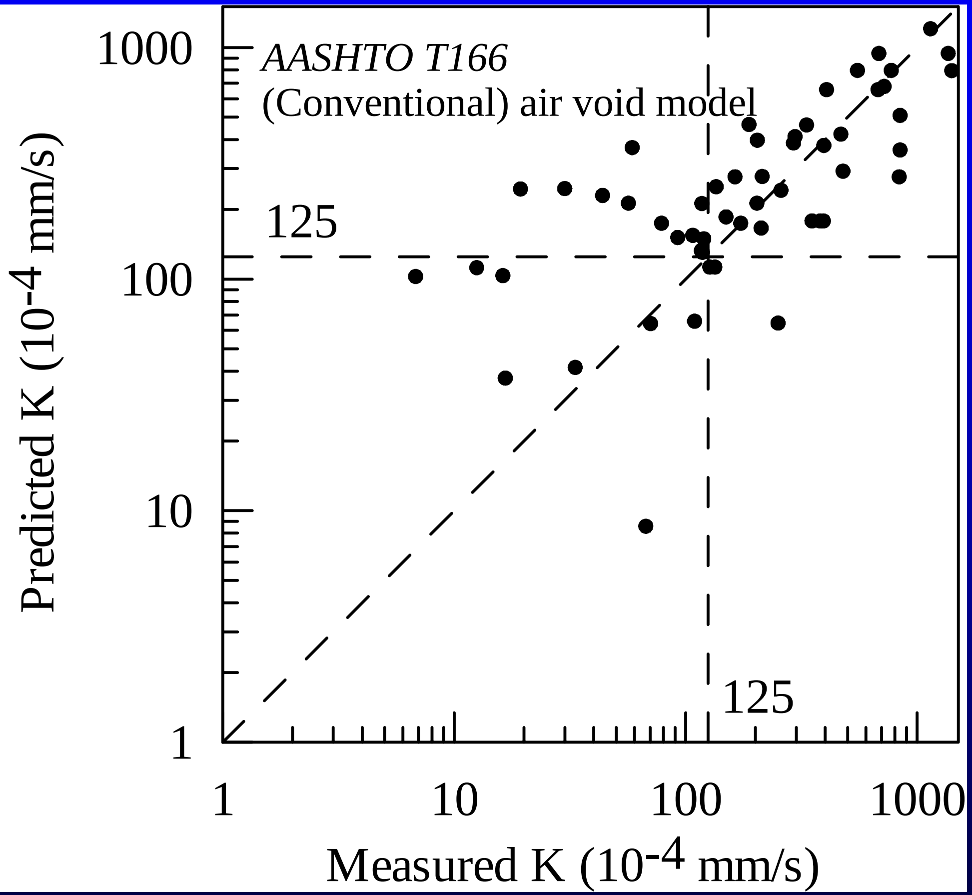


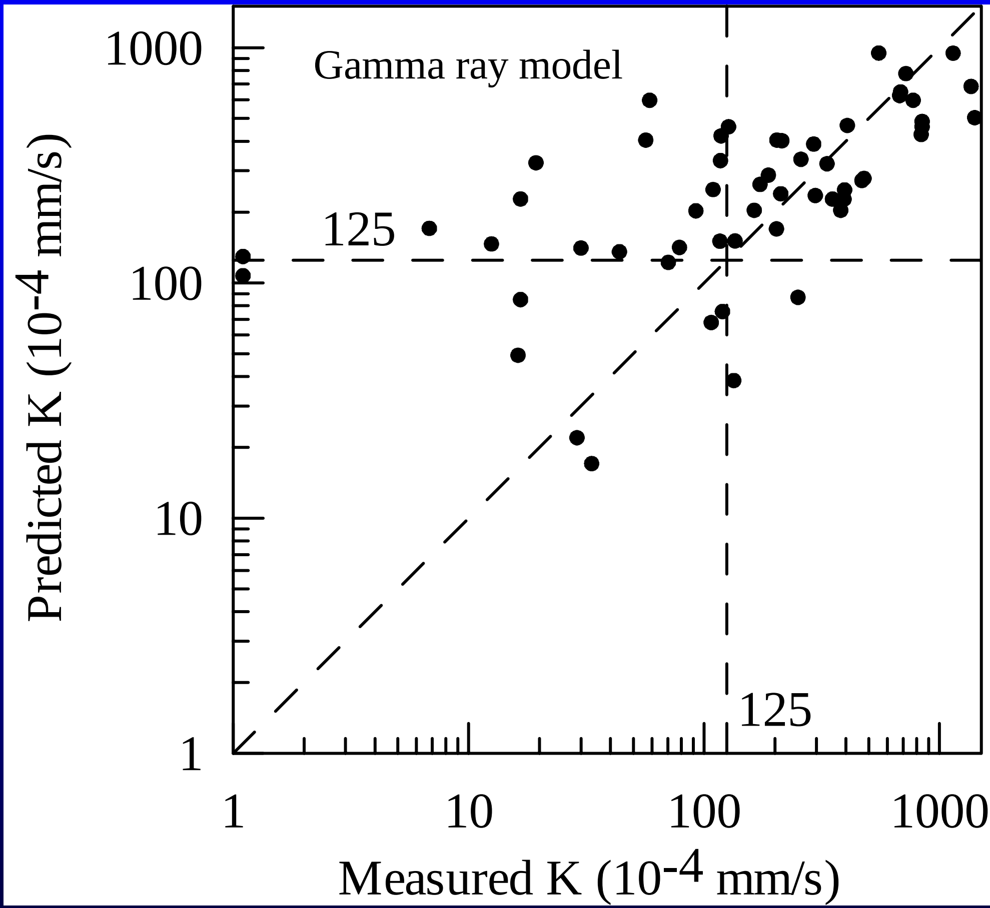


R^2=0.87, RMSE=0.0118

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> $125x10^{-4}$ 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
- ***Preliminary*** 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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