Stiffness issues related to structural design and interpretation of HVS results

HVS International Alliance
3rd Meeting – August 2005

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Overview of presentation

- General background
  - Why do we need “stiffness” data?
  - How do we define stiffness?
  - How do we model stiffness?
  - Why is it difficult to measure stiffness?
  - What is the effect of variable and inaccurate M_r results?
  - What are our sources of M_r data?
- HVS case studies
  - R2388 Cullinan
  - R243 Vereeniging
  - N7 Cape Town

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Stiffness issues related to structural design and interpretation of HVS results

General background

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Why do we need "stiffness" data

- Indicator of material quality
- We build solid mechanics models of pavements in an attempt to calculate stress and strain in the pavement
  - Mechanistic part of Mechanistic-Empirical design
    - Often based on static, linear elastic formulation
      - Multi-layer, integral transformation solutions (ELSYM5, BISAR, etc.)
      - Finite Element solutions (Michpave, etc.)
  - Some measure of "stiffness" is a required input

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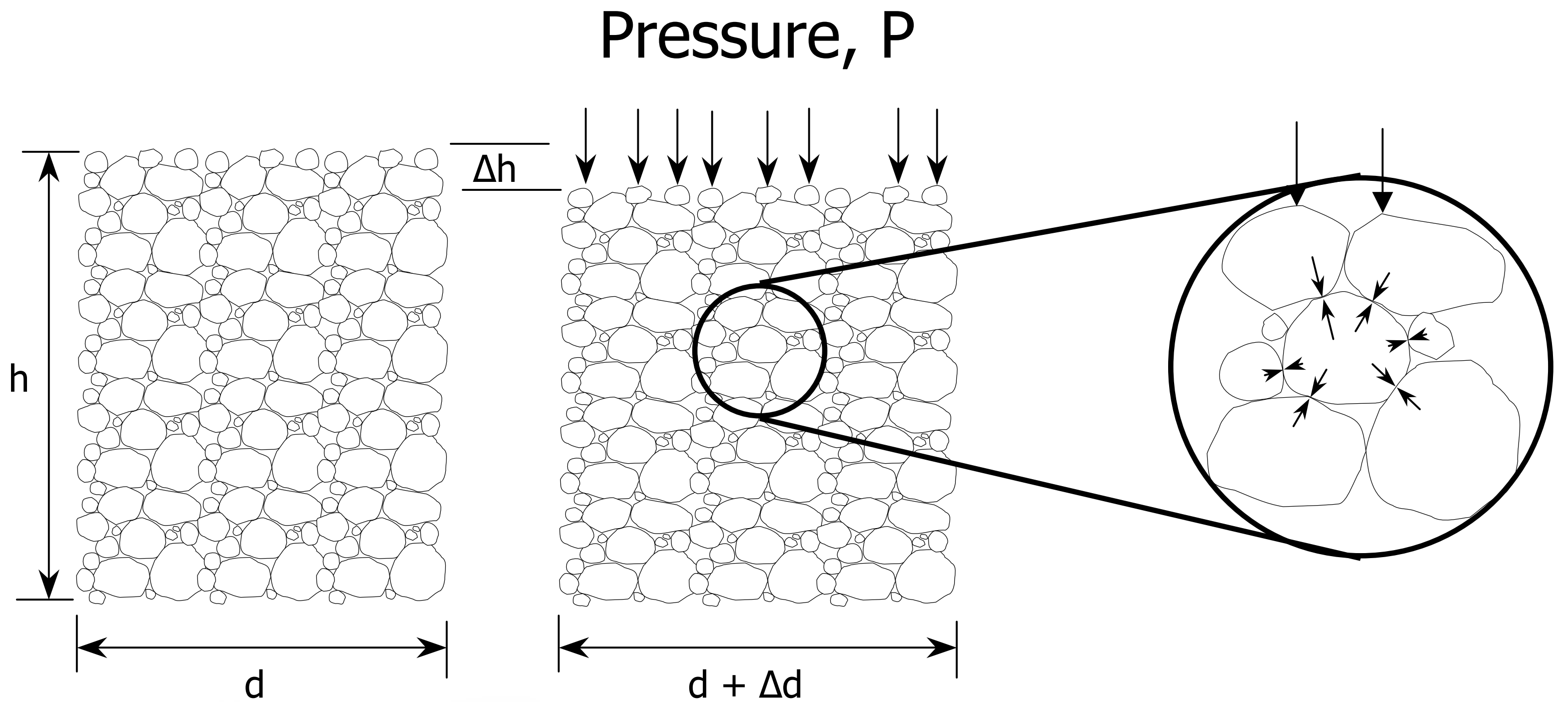
How do we define “stiffness”?

Real life, microscopic behaviour



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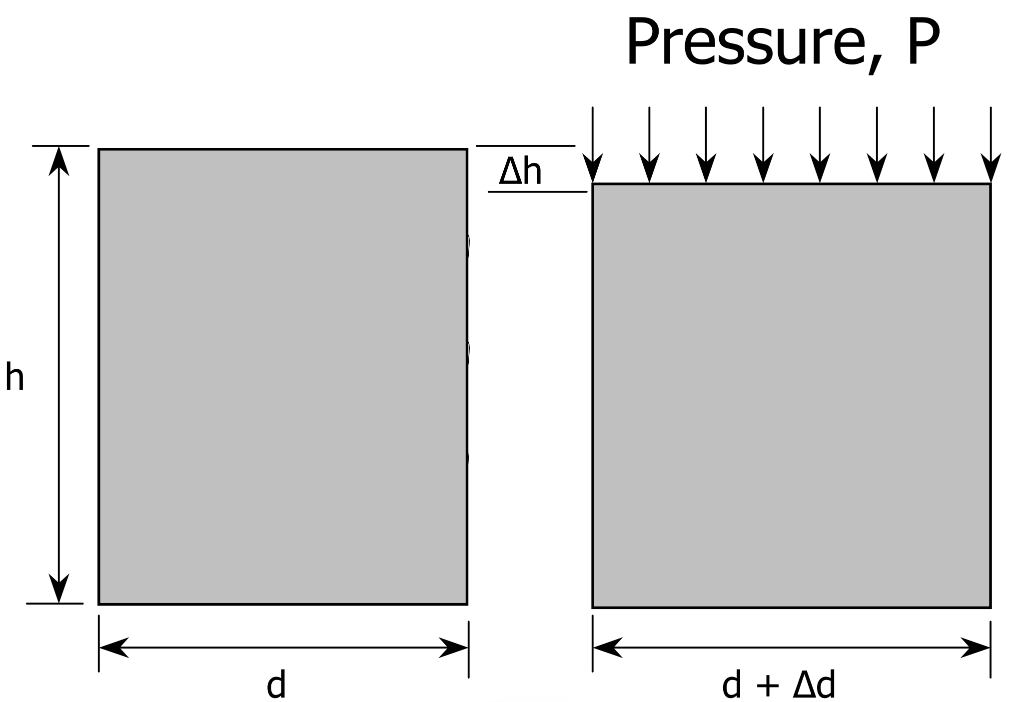
How do we define “stiffness”?

Solid mechanics, macroscopic model



$$\text{Stress} = \text{Pressure}$$

$$\text{Axial strain, } \varepsilon_x = \frac{\Delta h}{h}$$

$$Young's\ Modulus = \frac{Stress}{Strain}$$

$$Poisson's\ Ratio = \frac{\varepsilon_y}{\varepsilon_x}$$

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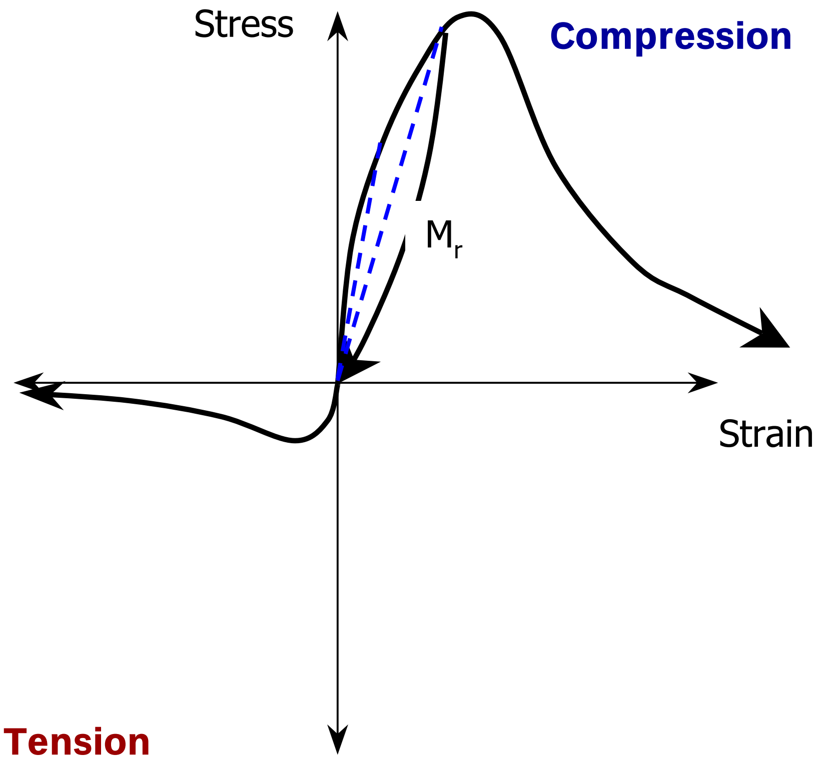
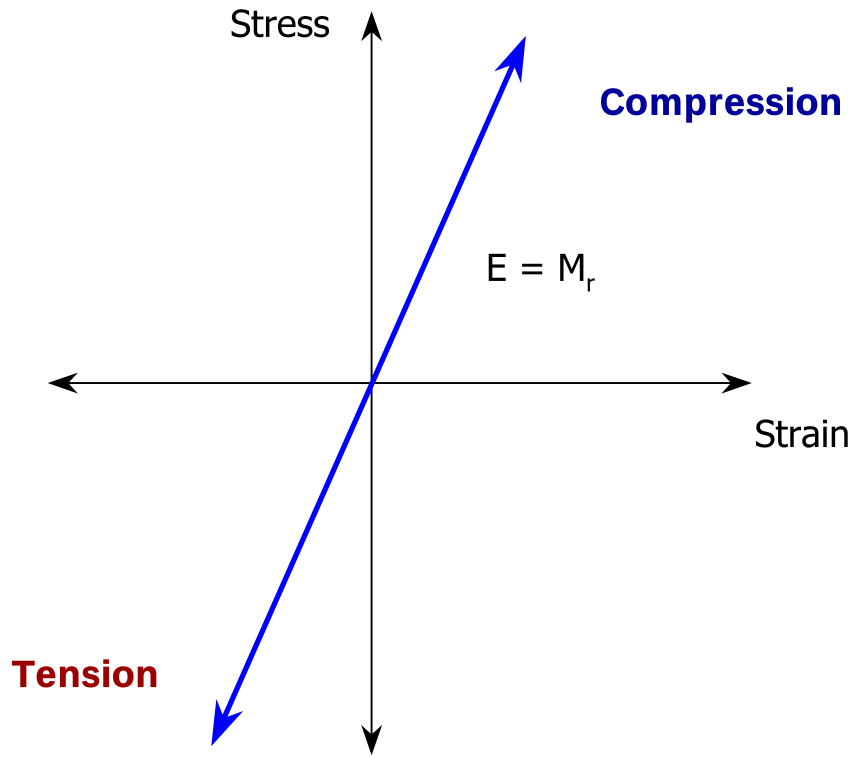
How do we model "stiffness"?

Real behaviour



Solid mechanics model



Why is it difficult to measure stiffness?

- Cannot measure stiffness
  - Measure stress and strain – calculate stiffness
  - Often include dynamic effects in measurement and calculate stiffness using static formulation
- Dependent on other variables
  - In general
    - Strain dependent
  - Unbound material
    - Density, saturation, stress and strain rate dependent
  - Asphalt concrete
    - Temperature and strain rate dependent

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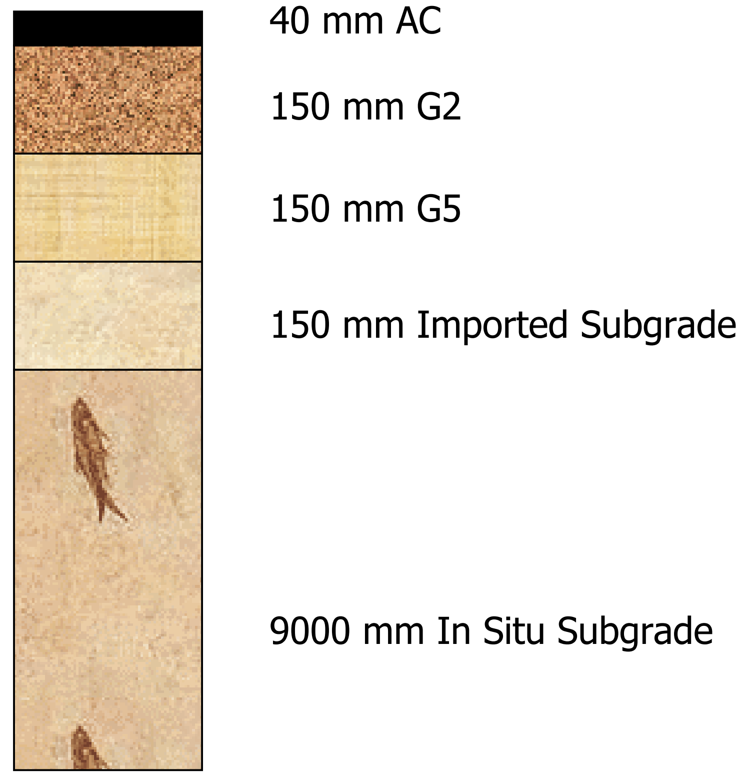
What is the effect of variable and inaccurate M_r results?

- Hypothetical test pavement
- Case 1
  - Base M_r
    - Average, 350 MPa
    - CoV, 15 %
- Case 2
  - Base M_r
    - Average, 550 MPa
    - CoV, 15 %



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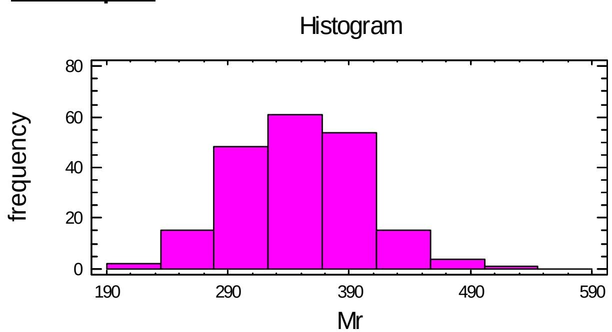
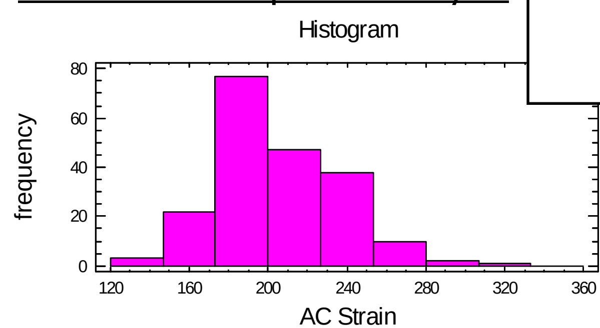
What is the effect of variable and inaccurate M_r results? Case 1

<u>ME input</u>



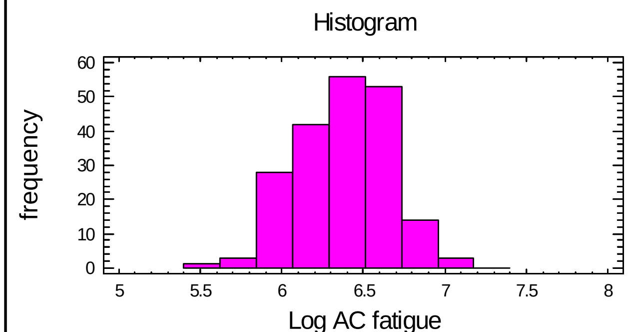
M_r = 348 MPa
CoV = 14,8 %
5th % = 269 MPa

<u>ME resilient response analysis</u>



AC Strain = 205 $\mu\varepsilon$
CoV = 15,3 %
95^{th} % = 257 $\mu\varepsilon$

<u>ME capacity estimate</u>



AC fatigue = 2,9 million axles
CoV = 69,4 %
5^{th} % = 0,85 million axles

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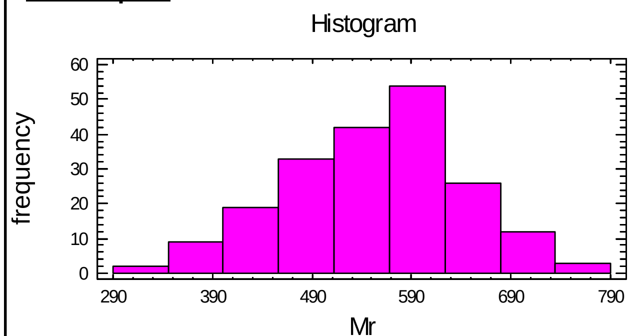
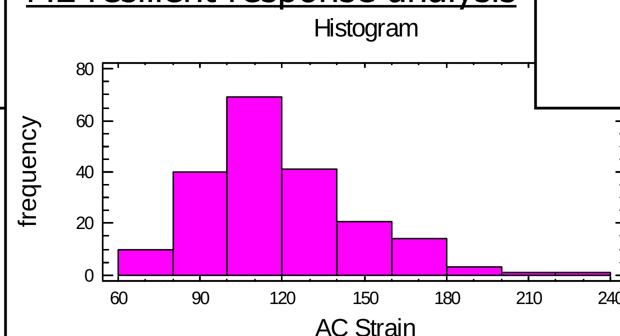
What is the effect of variable and inaccurate M_r results? Case 2

ME input



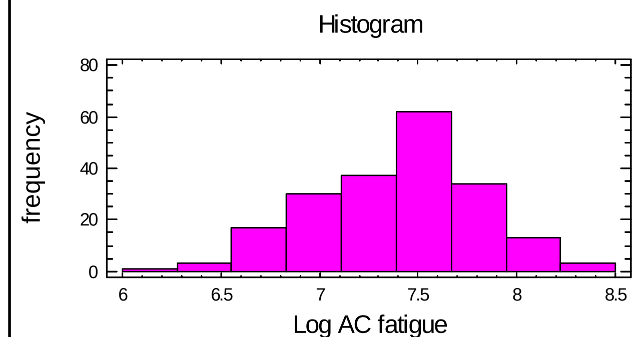
M_r = 554 MPa
CoV = 15,8 %
5th % = 398 MPa

ME resilient response analysis



AC Strain = 119 $\mu\varepsilon$
CoV = 23,6 %
95^{th} % = 175 $\mu\varepsilon$

ME capacity estimate



AC fatigue = 37,0 million axles
CoV = 95,9 %
5^{th} % = 4,4 million axles

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What is the effect of variable and inaccurate M_r results?

- M_r error
  - Case 1, M_r = 348 MPa
  - Case 2, M_r = 554 MPa
  - Error = 206 MPa
- AC fatigue design error
  - Case 1, Mr = 0,85 miSA (ES1 design class)
  - Case 2, Mr = 4,40 miSA (ES3 design class)
  - Error = 3,55 miSA

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Potential sources of M_r data?

- Laboratory testing
  - Dynamic tri-axial
  - Flexural beam
- Field testing
  - Falling Weight Deflectometer (FWD)
  - Multi-Depth (MDD)
  - Seismic

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Stiffness issues related to structural design and interpretation of HVS results

Case studies

R2388 Cullinan

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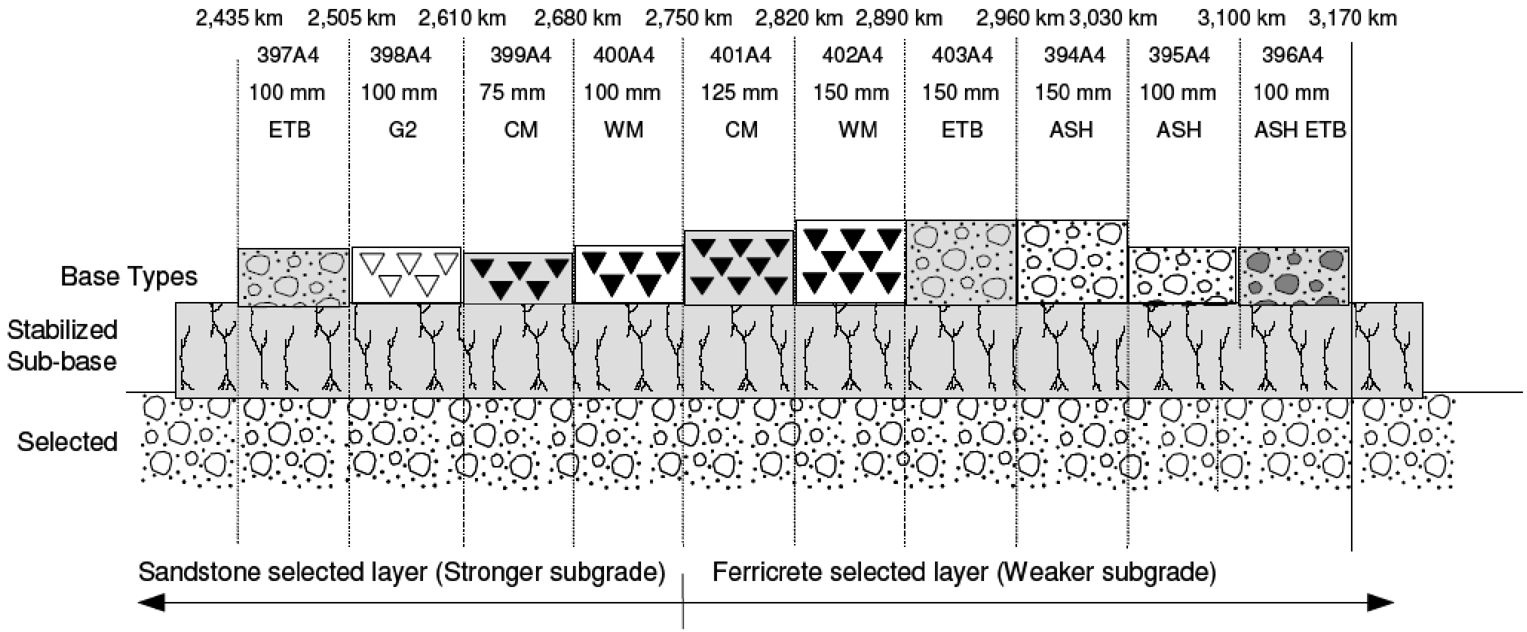
R2388 Test pavements



G2: Crushed stone
ETB: Emulsion Treated Base (Natural gravel)
ASH ETB: Emulsion Treated Base (SASOL ash)
ASH: SASOL ash
WM: Waterbound Macadam
CM: Composite Macadam

HVS1B-Cullinan-1.ppt

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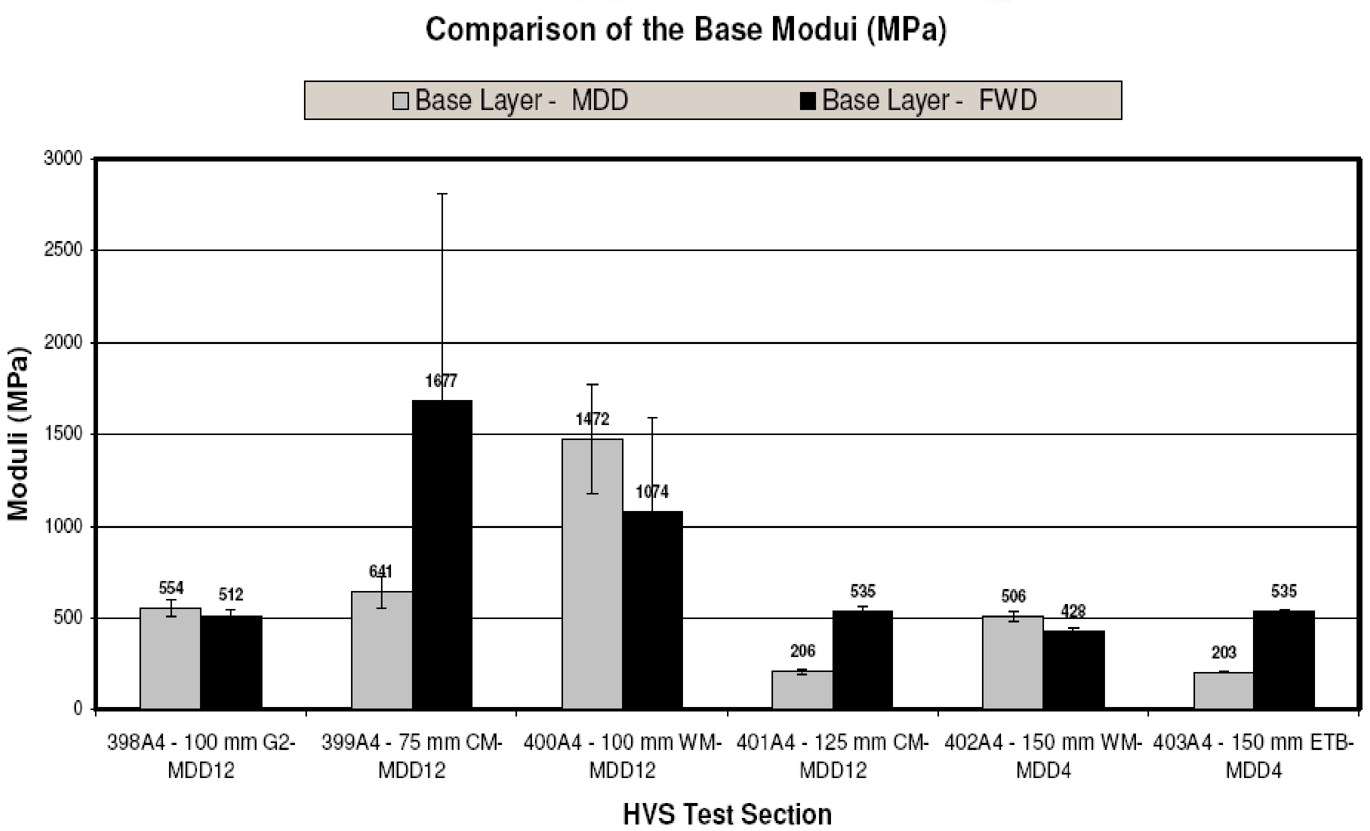
R2388 Base M_r



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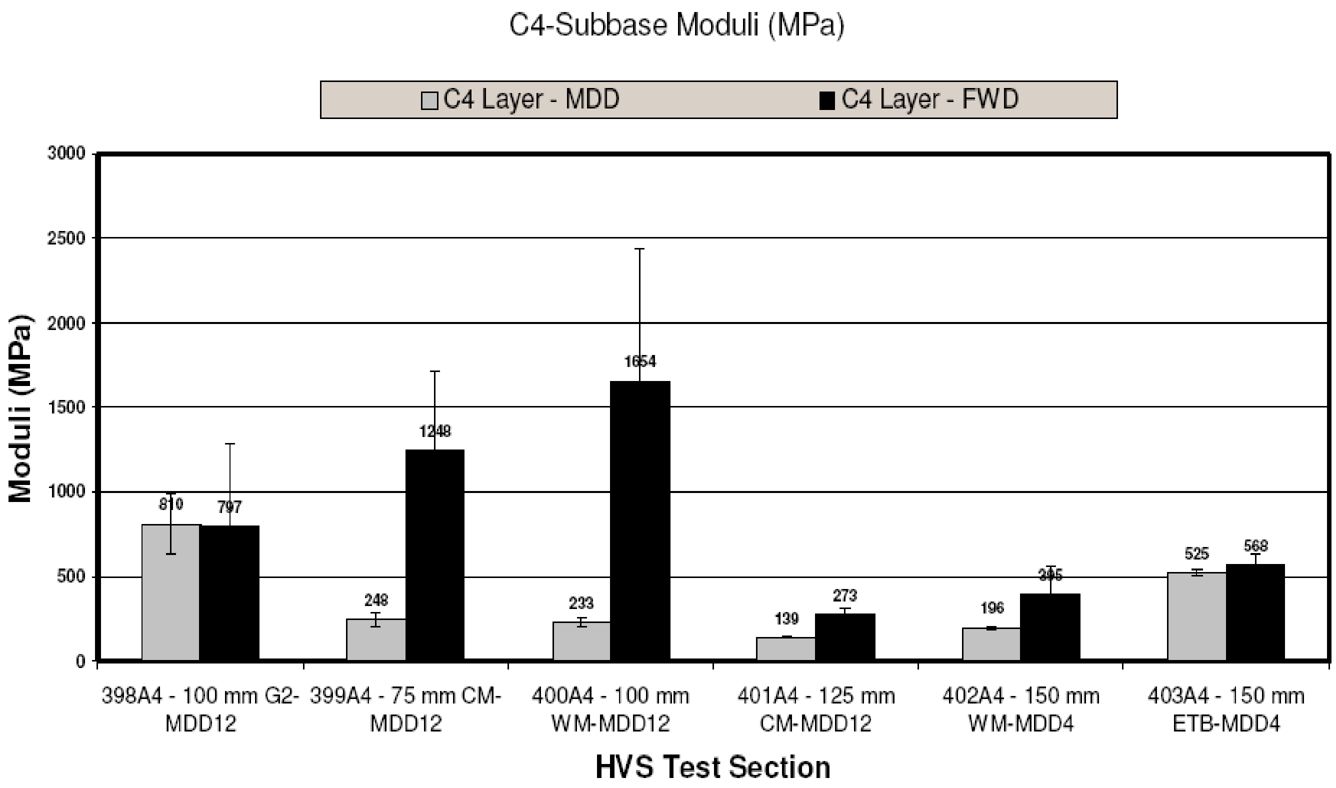
R2388 Subbase M_r



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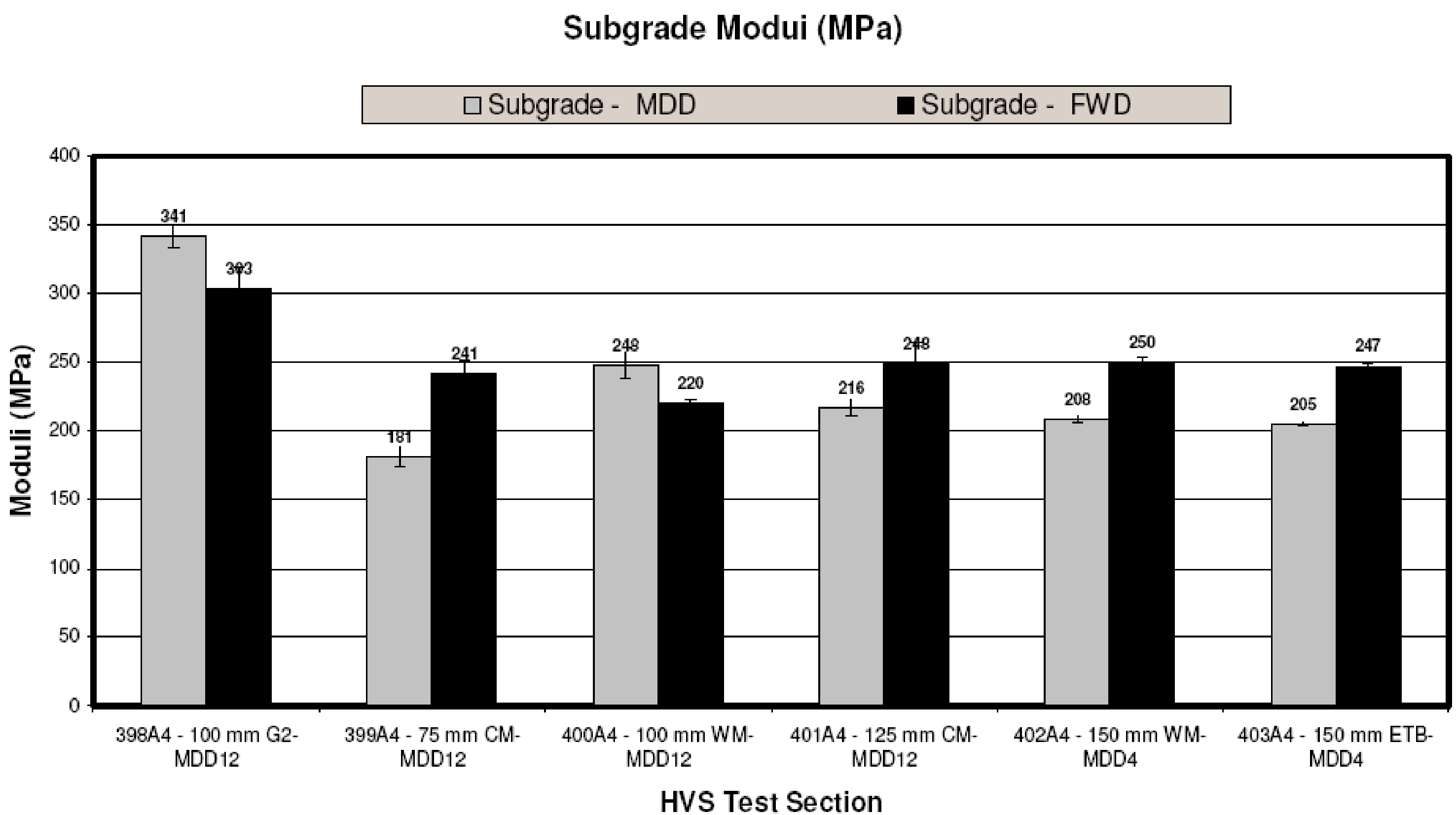
R2388 Subgrade M_r



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Stiffness issues related to structural design and interpretation of HVS results

Case studies
R243 Vereeniging

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R243 Test pavements

Before rehabilitation

After rehabilitation

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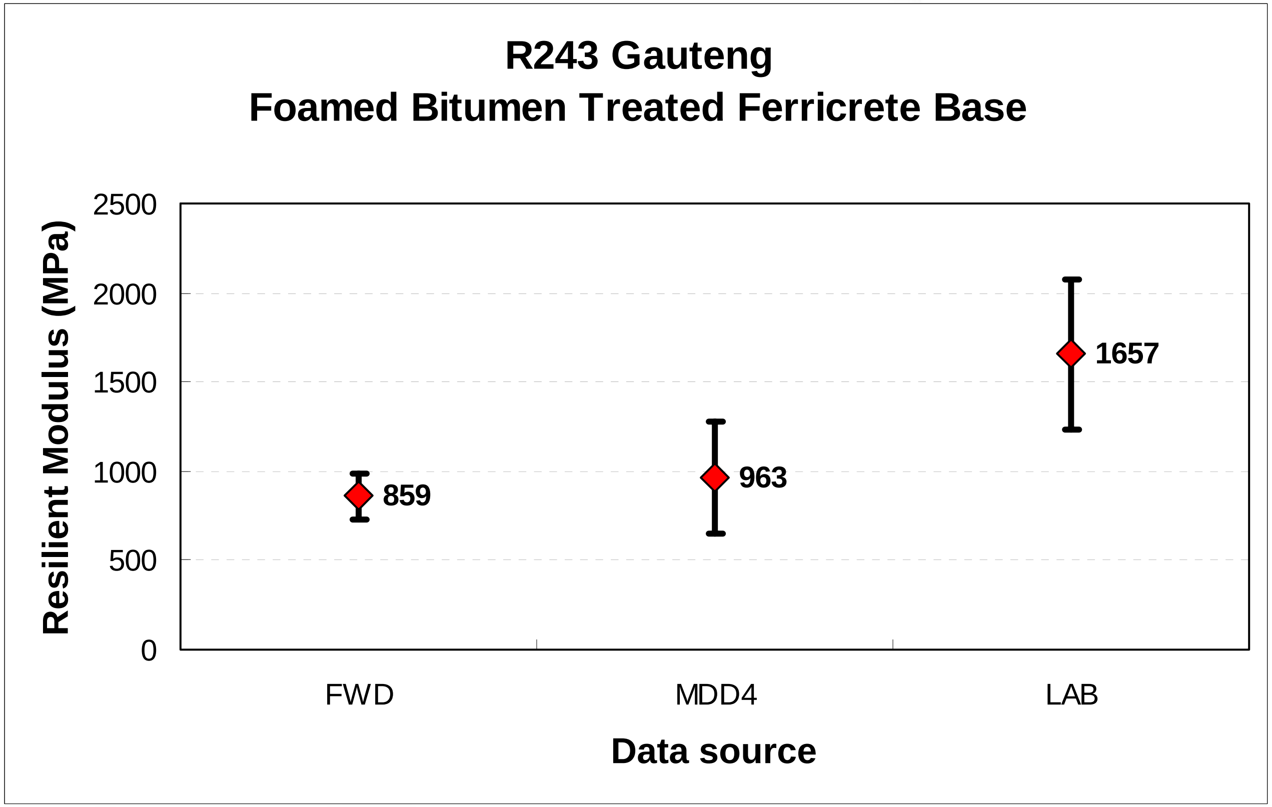
R243 Foamed Bitumen Treated M_r



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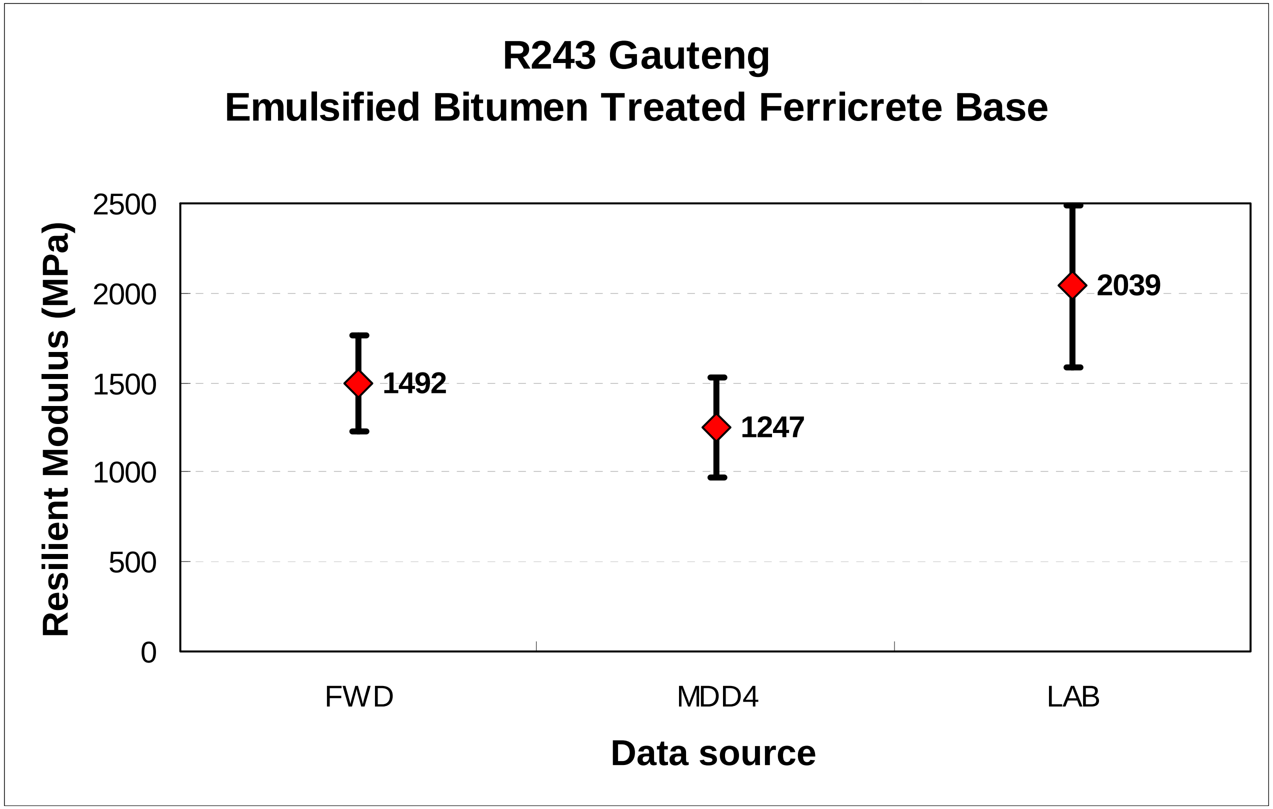
R243 Emulsified Bitumen Treated M_r



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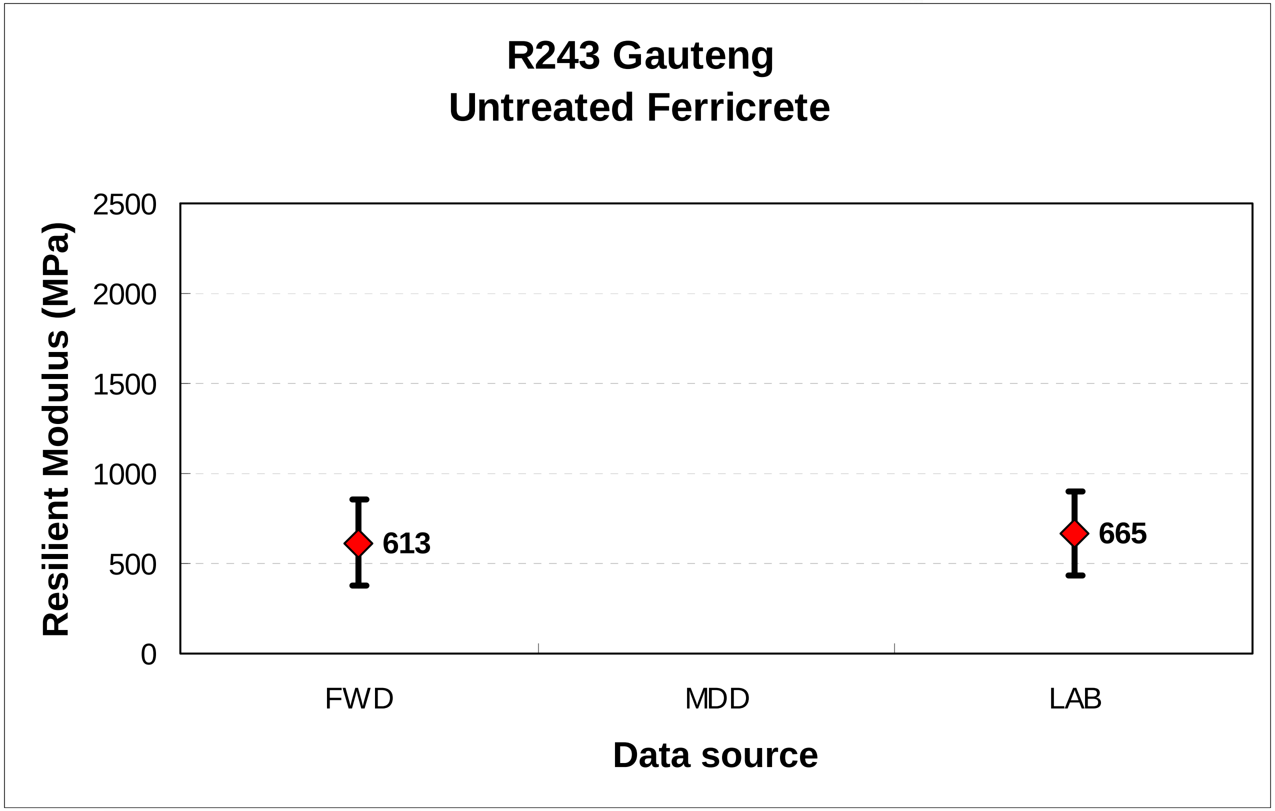
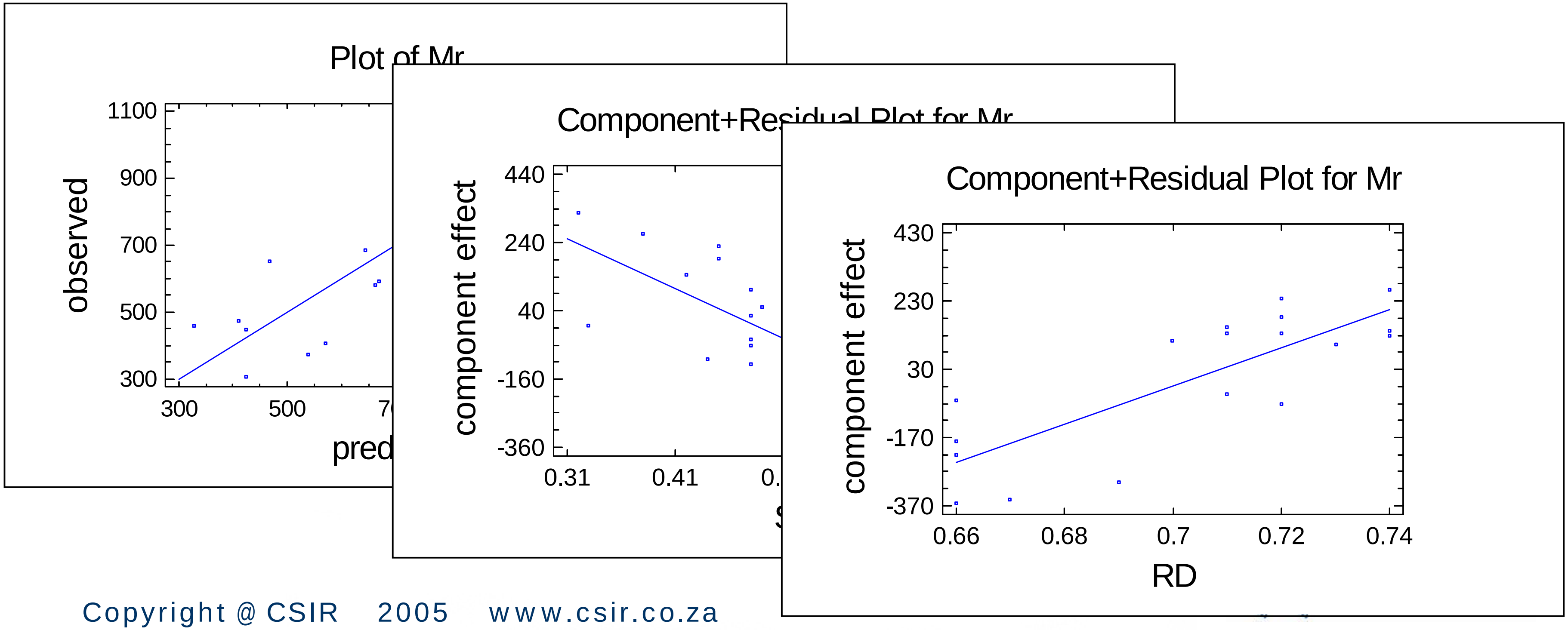
R243 "Untreated" M_r



R243 Laboratory M_r

- Regression analysis of Mr data with Relative Density and Degree of Saturation as variables
  - R^2 = 74 %
  - RD and S significant at 99 % confidence level



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Stiffness issues related to structural design and interpretation of HVS results

Case studies

N7 Cape Town

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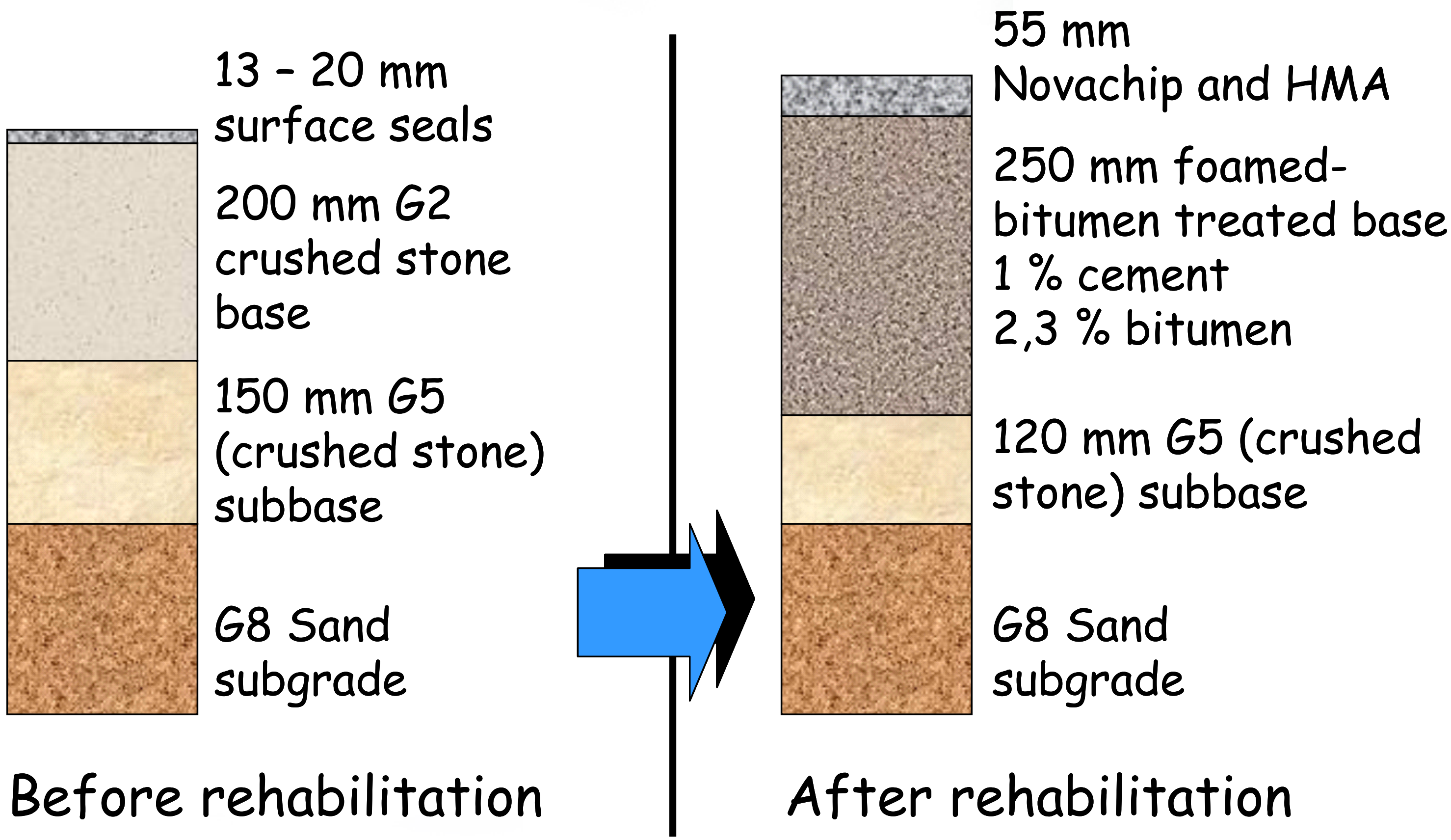
N7 Test pavements



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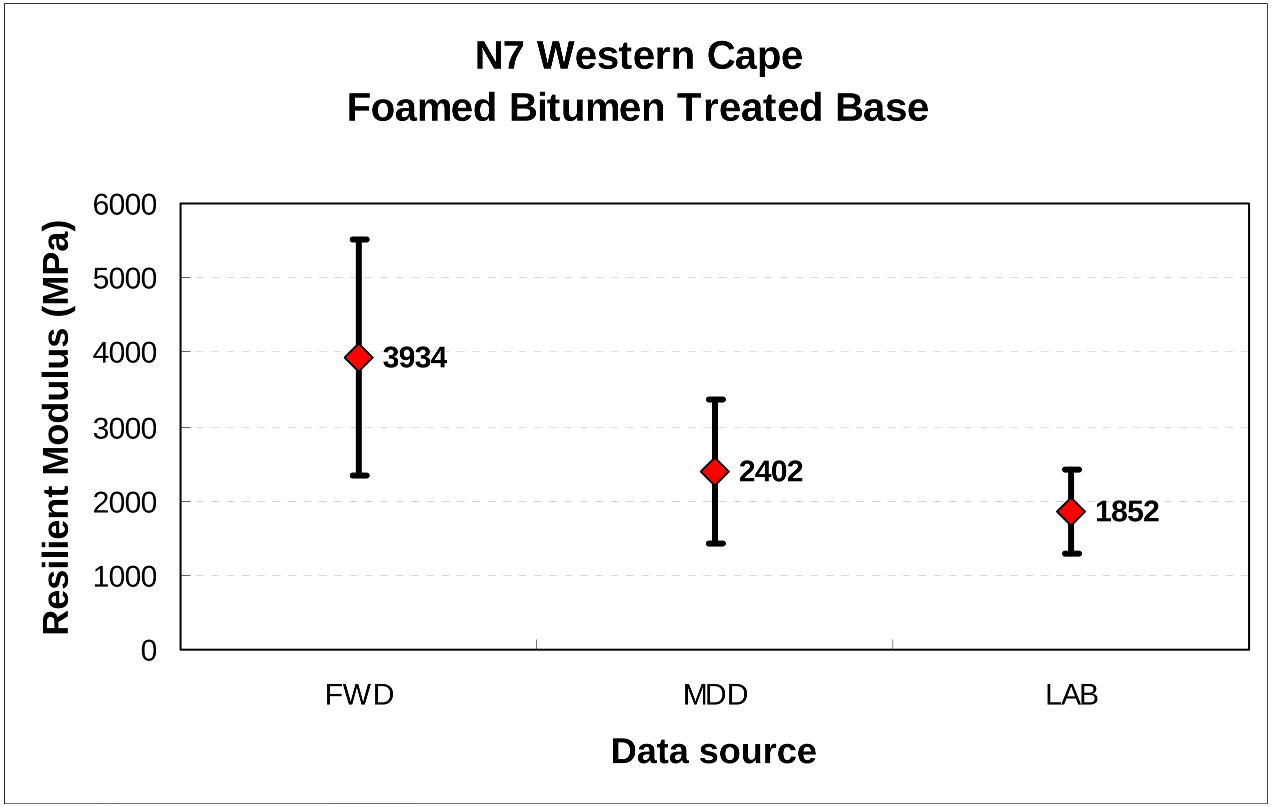
N7 Foamed Bitumen Treated M_r



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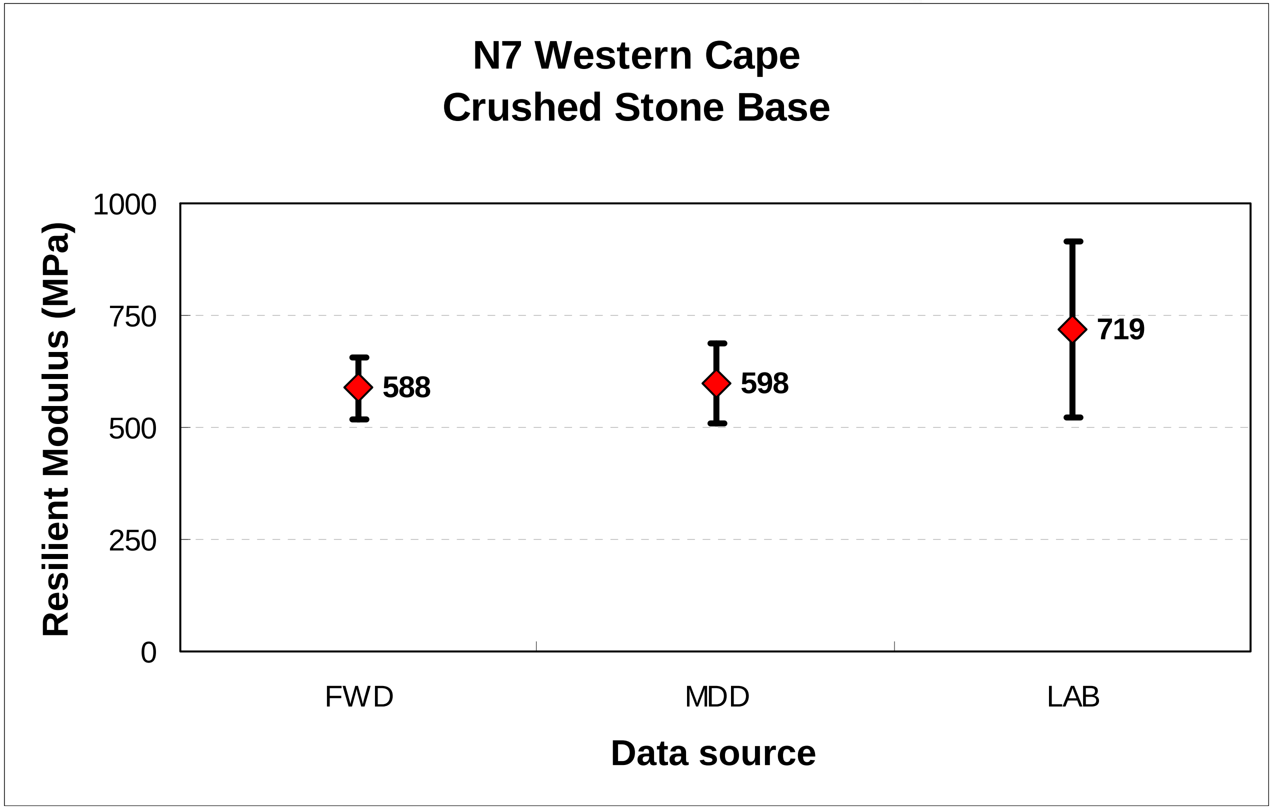
N7 Untreated M_r



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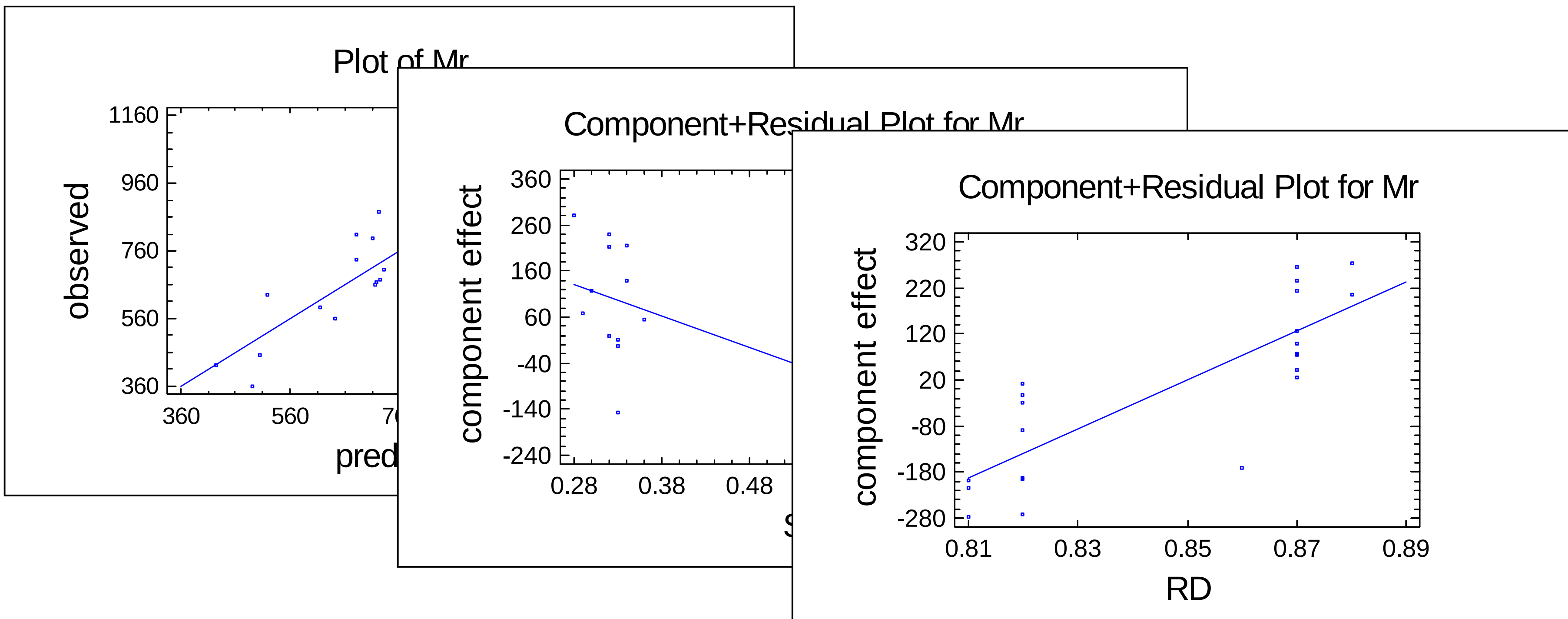
N7 Laboratory M_r

- Regression analysis of Mr data with Relative Density and Degree of Saturation as variables
  - R^2 = 73 %
  - RD and S significant at 99 % confidence level



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Summary

- Our solid mechanics model is a poor approximation of actual behaviour
- The ME design process magnifies variability and error from input variability, to resilient response variability, to structural capacity estimation
- M_r results seem to distinguish sufficiently between unbound and stabilized material
- M_r results from different sources agree better for unbound material than stabilised material
- <u>M_r results depend on so may variables</u> – be careful of direct comparison between M_r data from different sources if the test conditions are not the same

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The way forward

- Discussion
  - How serious is the problem?
    - Classification of material
    - ME design
  - Should we be looking for exact agreement or general consensus?
  - Is it possible to incorporate all the important variables to enable ME design?
  - How do we establish a benchmark to asses accuracy?

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