Use of MDD depth deflection data

Case study:
Structural design models for pavement materials stabilised with foamed bitumen

CSIR TRANSPORTEK

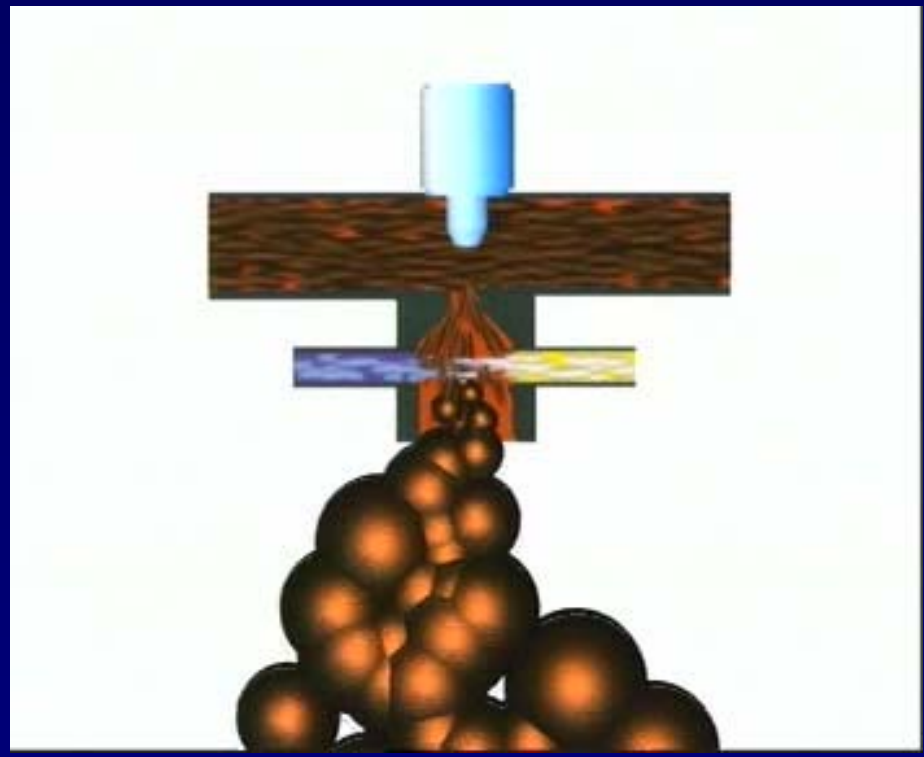
Scope

- Introduction to deep in situ recycling (DISR)
  - Stabilisation with foamed bitumen
- Objectives of the study
- Data to identify and quantify modes of structural distress
  - HVS test results
  - Laboratory test results
- Structural design models
  - For mechanistic-empirical design method

Foamed bitumen

Hot bitumen

Cold water



Air

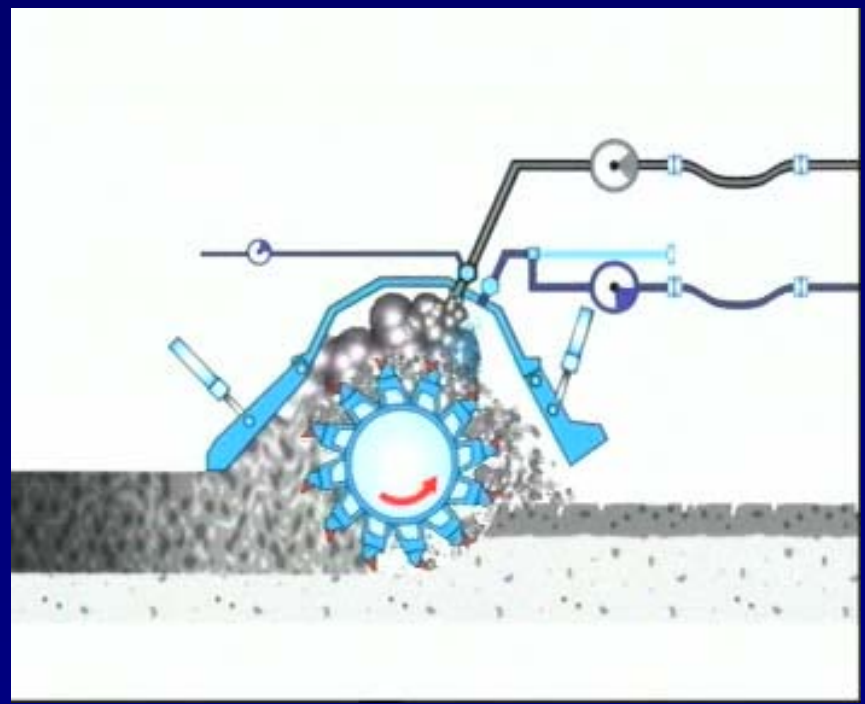
Expansion chamber

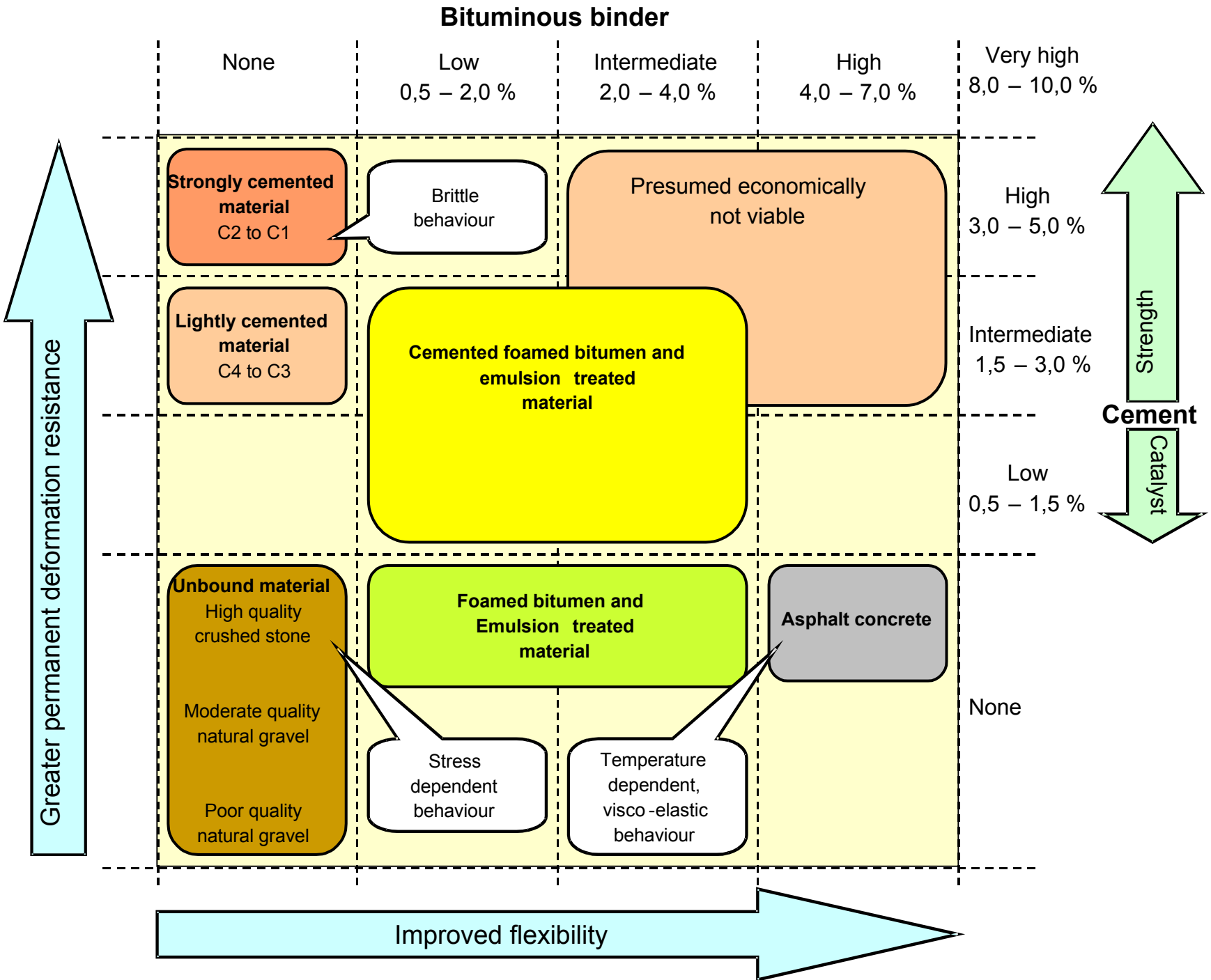
Foam

- Expanded volume aids distribution during mixing
- Also called “foamed asphalt”

Why DISR with stabilisation?

- Shift from new construction to rehabilitation
- Quick process, re-open within a day
- Economical (*World Highways, April 2001*)
- Stabilisation allows use of marginal aggregates
- Environmentally friendly
  - Re-use existing materials
  - Lower heating energy requirements
  - Lower emissions during construction




Bituminous binder
None
Low
0,5 – 2,0 %
Intermediate
2,0 – 4,0 %
High
4,0 – 7,0 %
Very high
8,0 – 10,0 %
Strongly cemented material
C2 to C1
Brittle behaviour
Presumed economically not viable
High
3,0 – 5,0 %
Lightly cemented material
C4 to C3
Cemented foamed bitumen and emulsion treated material
Intermediate
1,5 – 3,0 %
Low
0,5 – 1,5 %
Unbound material
High quality crushed stone
Moderate quality natural gravel
Poor quality natural gravel
Foamed bitumen and Emulsion treated material
Asphalt concrete
None
Stress dependent behaviour
Temperature dependent, visco -elastic behaviour
Greater permanent deformation resistance
Strength
Cement
Catalyst
Improved flexibility

Objectives of the HVS study

- Determine structural adequacy of bituminous stabilised materials
- Understand material behaviour
  - Influence of stabilising material
  - Measure engineering properties
- Develop structural design models
  - South African Mechanistic-Empirical Design Method
- How?
  - Laboratory tests
  - Heavy Vehicle Simulator tests
    - » *Predominantly using MDD depth deflection and permanent deformation data*

Background information

- Actual road considered for rehabilitation
  - DISR with foamed bitumen stabilisation
- Experimental sections for HVS testing
  - 100 m foamed bitumen treatment
  - 100 m emulsion treatment
  - *Just finished two more foamed bitumen treated sections at different location, different material*
- Material dry-milled for laboratory test programme
  - Old cement treated ferricrete base
  - Existing multiple seal surfacing
  - Some untreated ferricrete subbase

Background information: Pavement structure

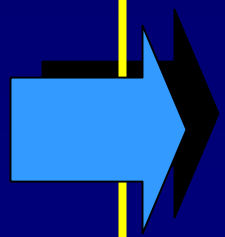
15 mm surface seals

150 mm Cement-treated base

150 mm Cement-treated subbase

Subgrade

Before rehabilitation



30 mm HMA

250 mm Emulsion/ foamed bitumen treated base
2 % cement
1,8 % bitumen

65 mm Cement-treated subbase

Subgrade

After rehabilitation

Background information: Recycled material data

- HVS test sections
  - 2 % cement
  - 1.8 % bitumen

- Laboratory tests
  - No treatment
  - 0, 1, 2 % cement
  - 0, 1.8, 3.0, 5.0 % foamed bitumen

HVS Tests

- 2 HVS test sections per material
  - Foamed bitumen
  - Emulsion
- 3 Wheel loads
- Instrumentation
  - MDDs
  - RSD
  - Laser profilometer

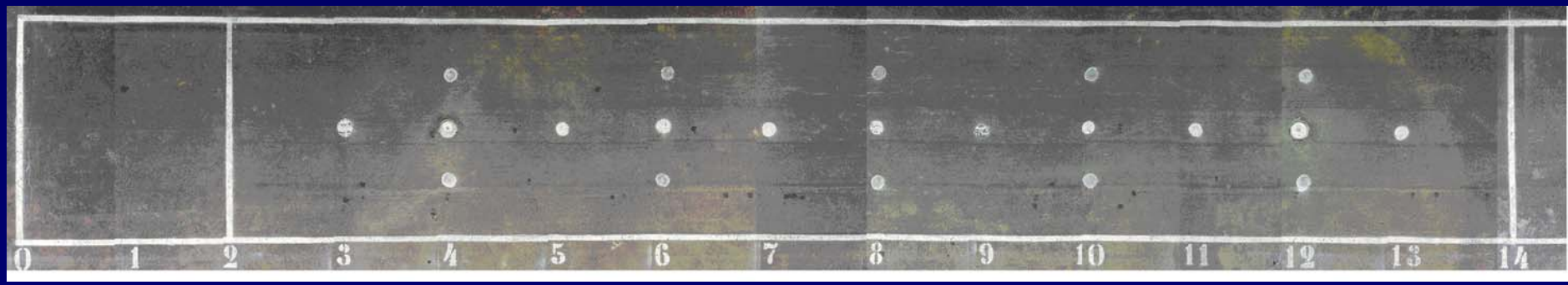
HVS test program

- Foamed bitumen treated material

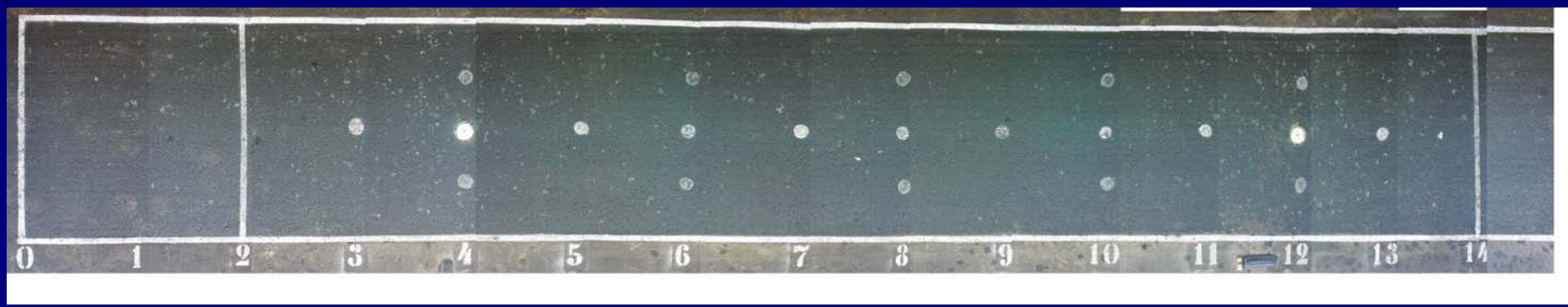
Phase	I			II		
Test number	409A4	409B4	409B4 (wet)	411A4		411A4 (wet)
Wheel load [kN]	80	100	100	40	80	80
Tyre Inflation pressure [kPa]	800	850	850	620	800	800
Load applications	307 224	142 650	12 695	958 714	340 883	14 048

HVS test results: Visual condition, 409A4

N10

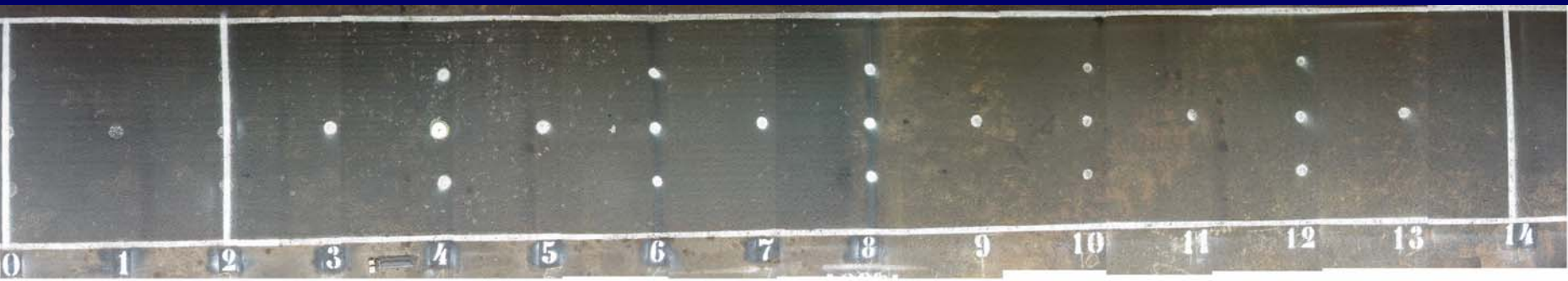


N307 224

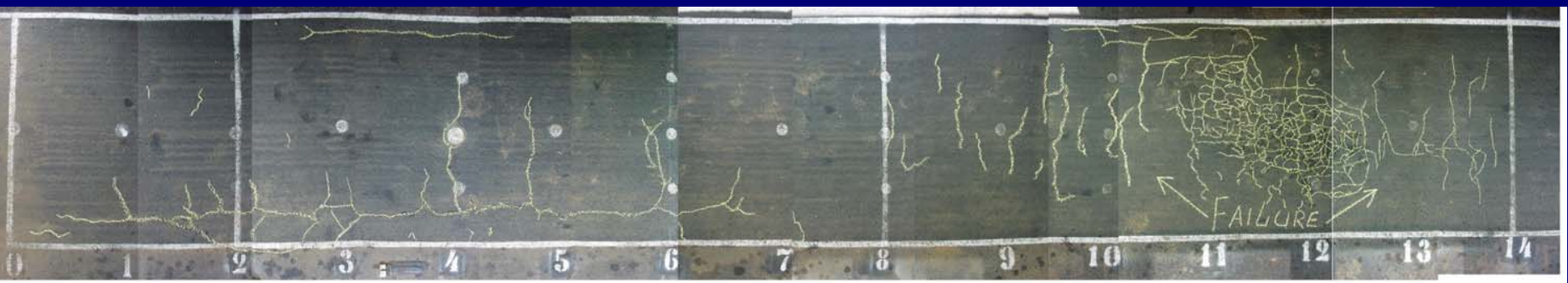


HVS test results: Visual condition, 409B4

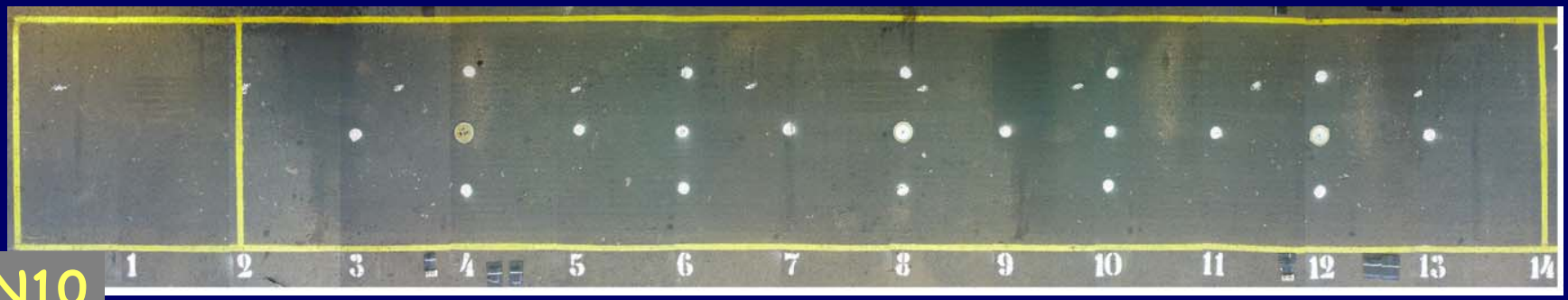
N10



N155 300



HVS test results: Visual condition, 411A4



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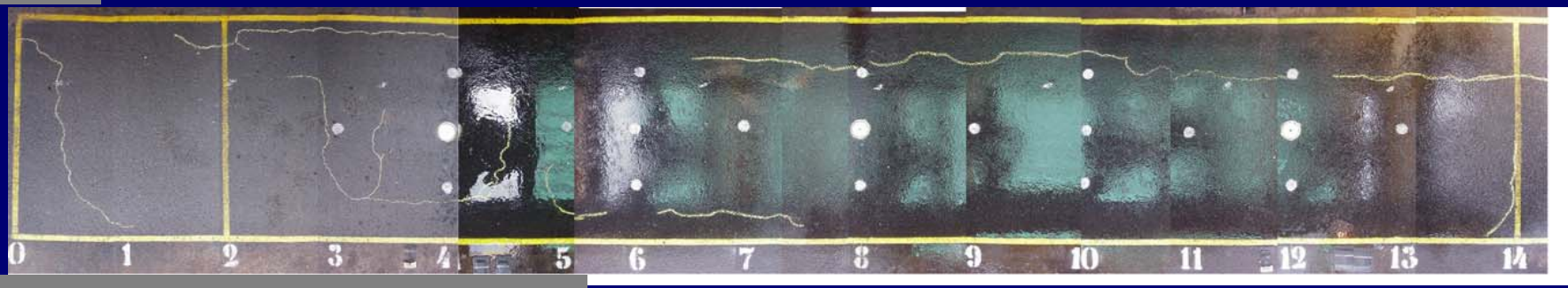
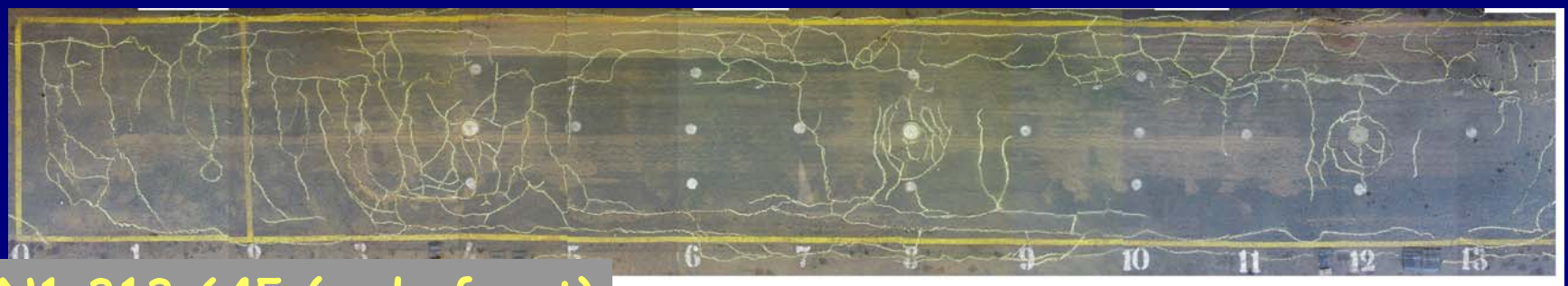
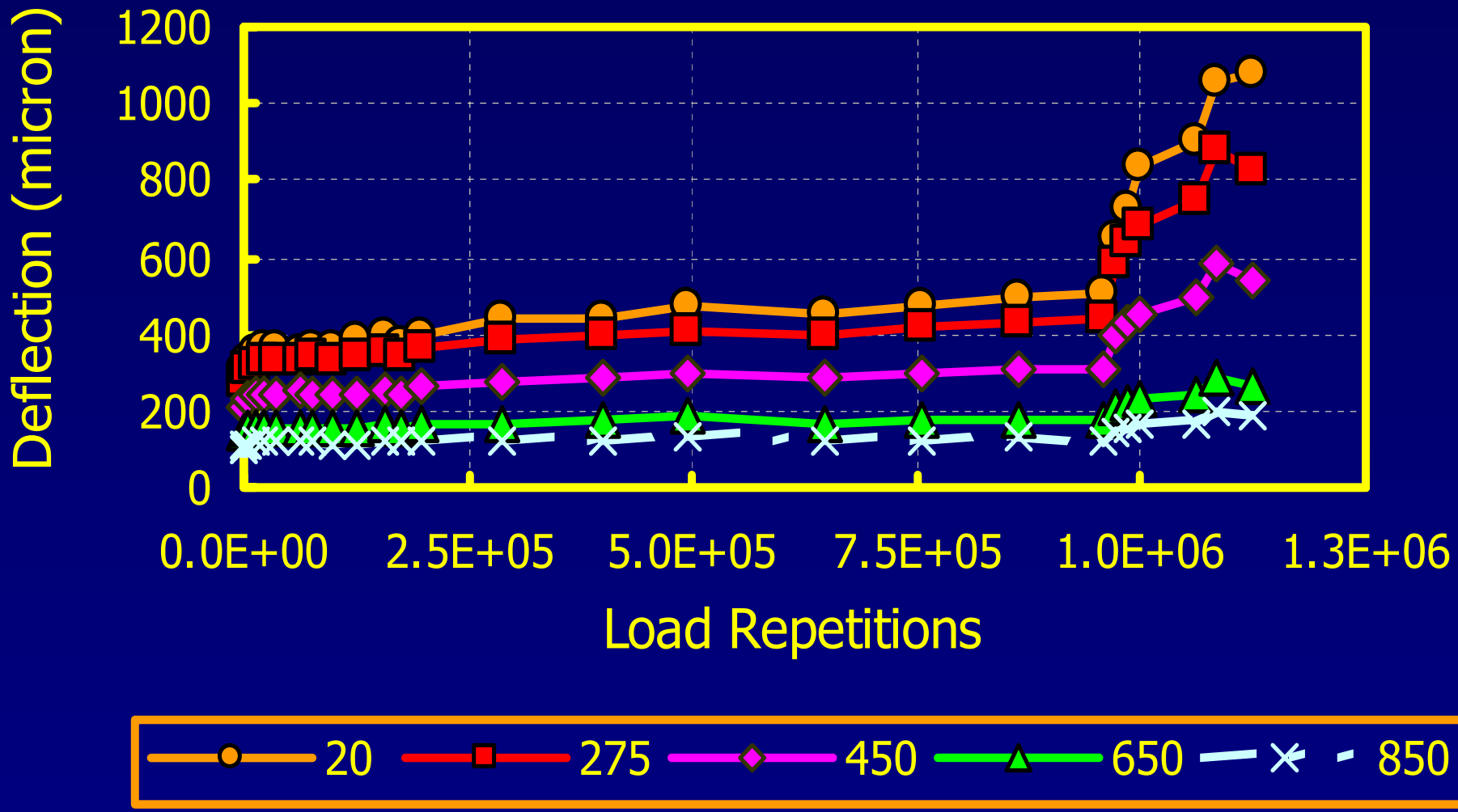


N1 299 597 (end of dry)

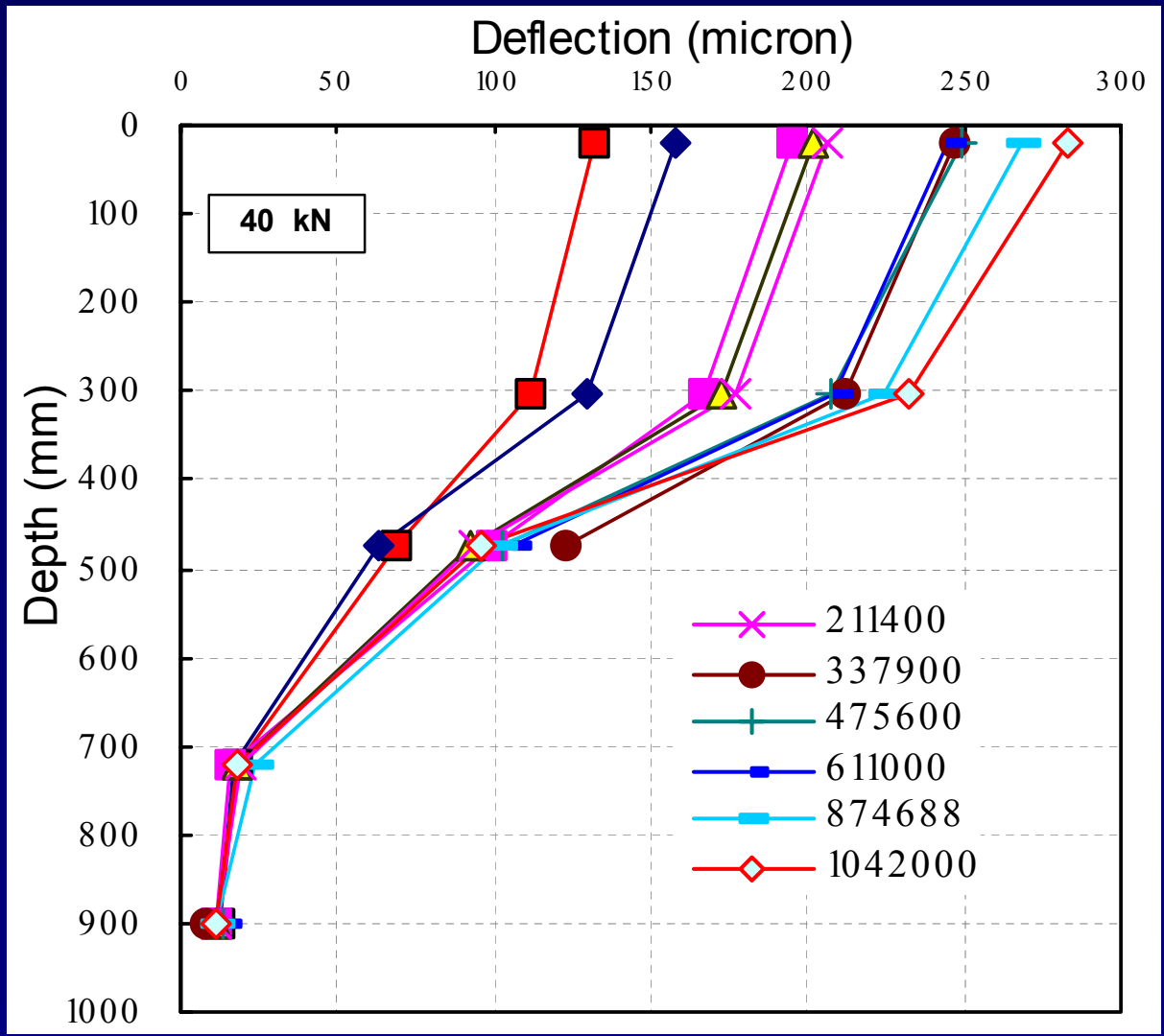


N1 313 645 (end of wet)

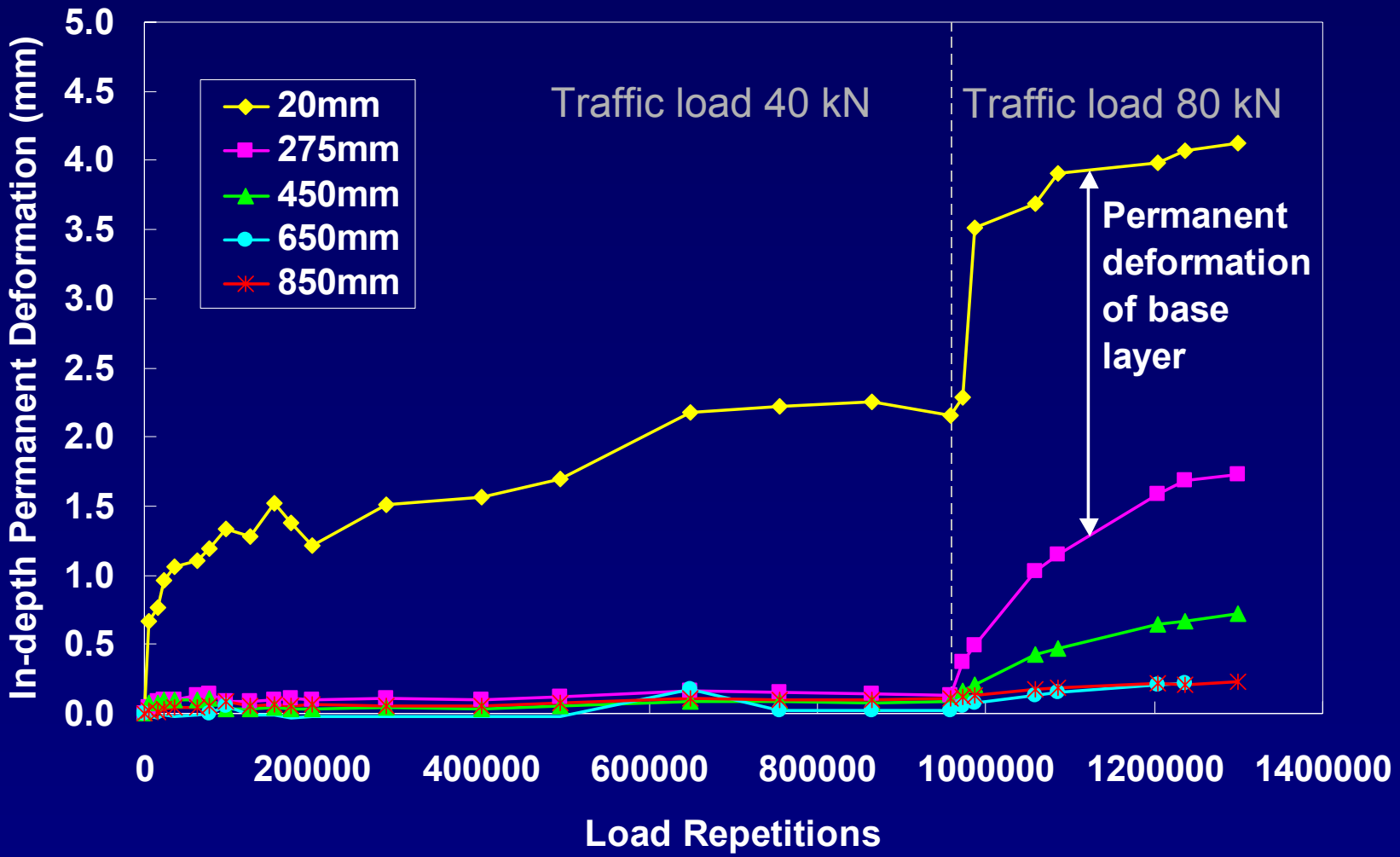
HVS test results: Depth deflection



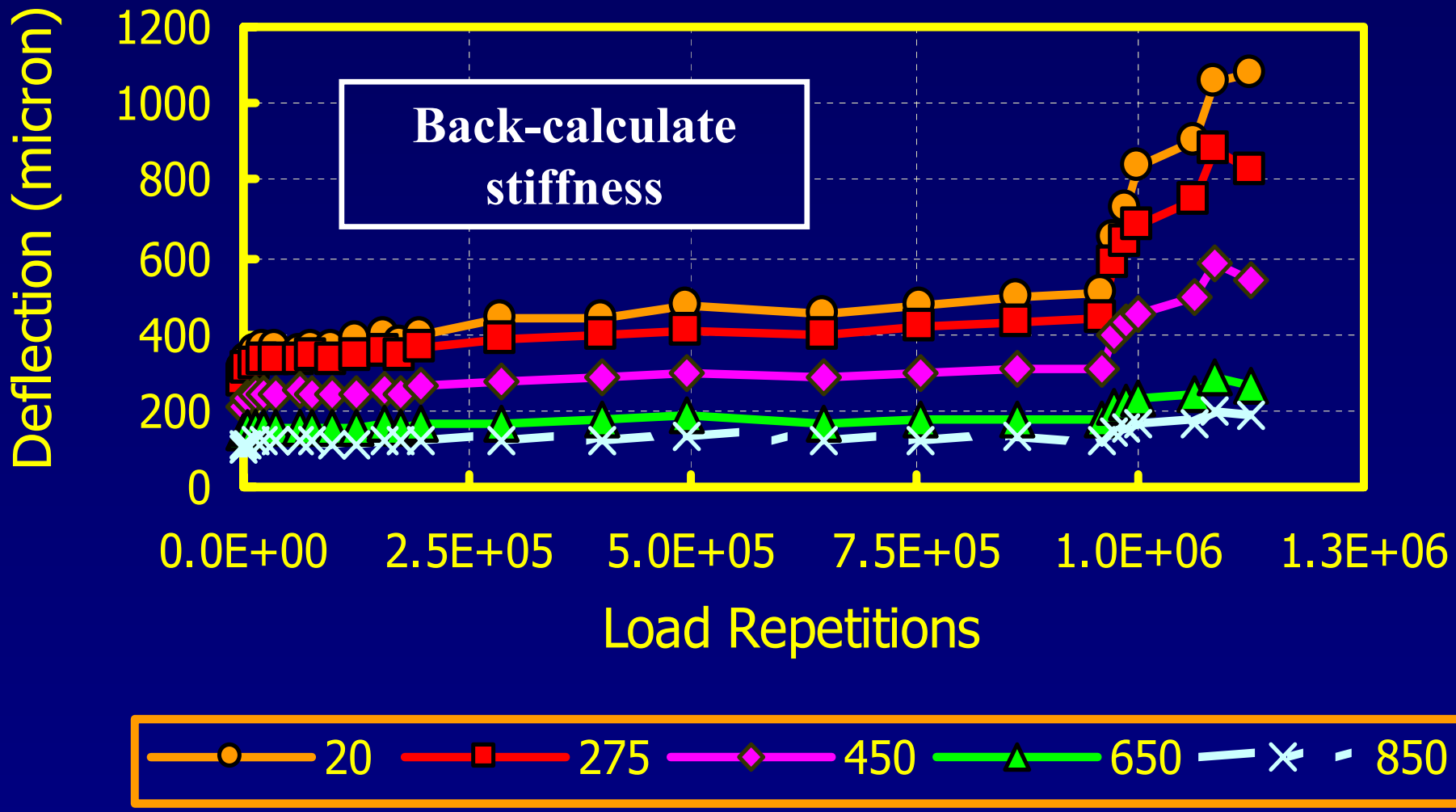
HVS test results: Depth deflection



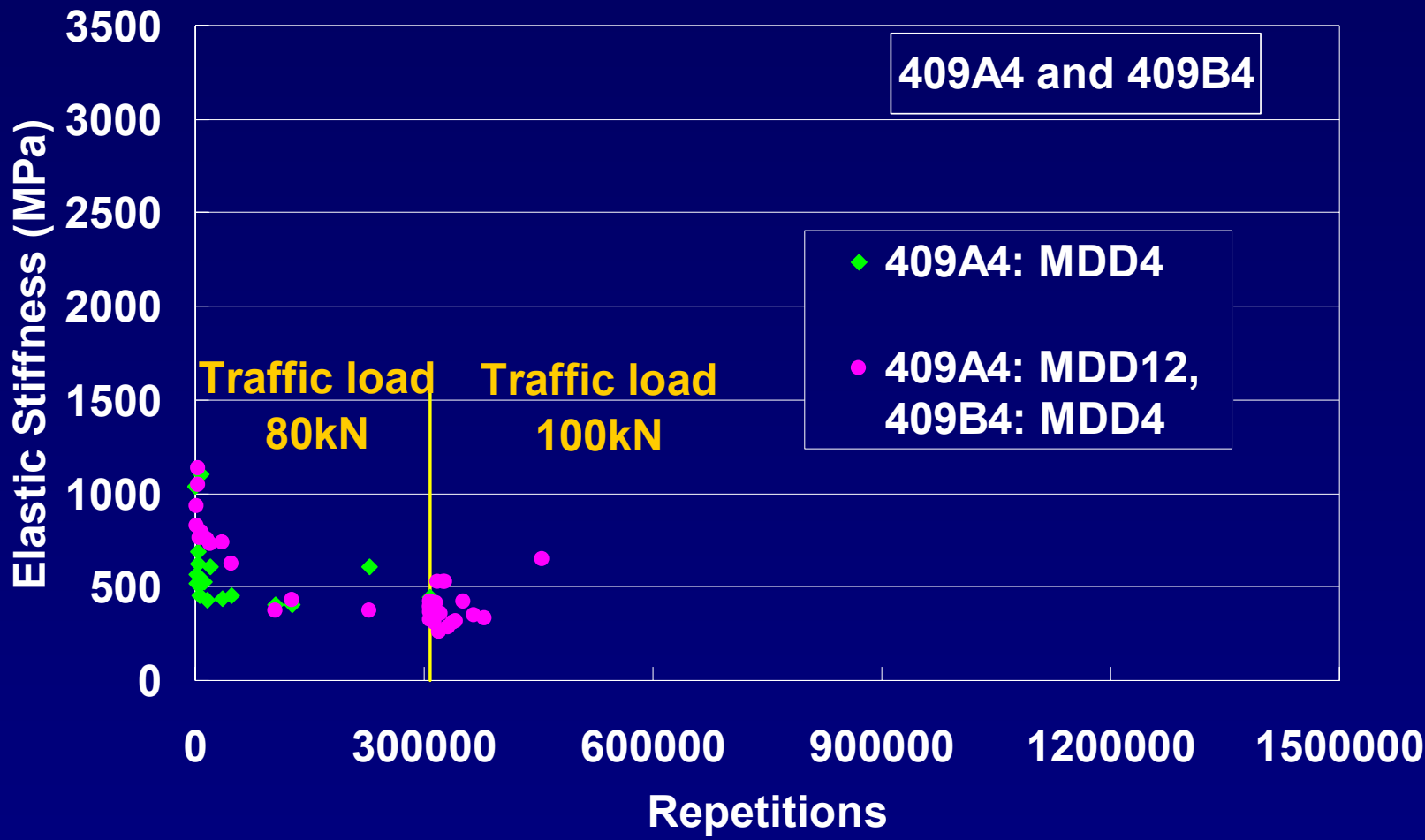
HVS test results: In-depth PD



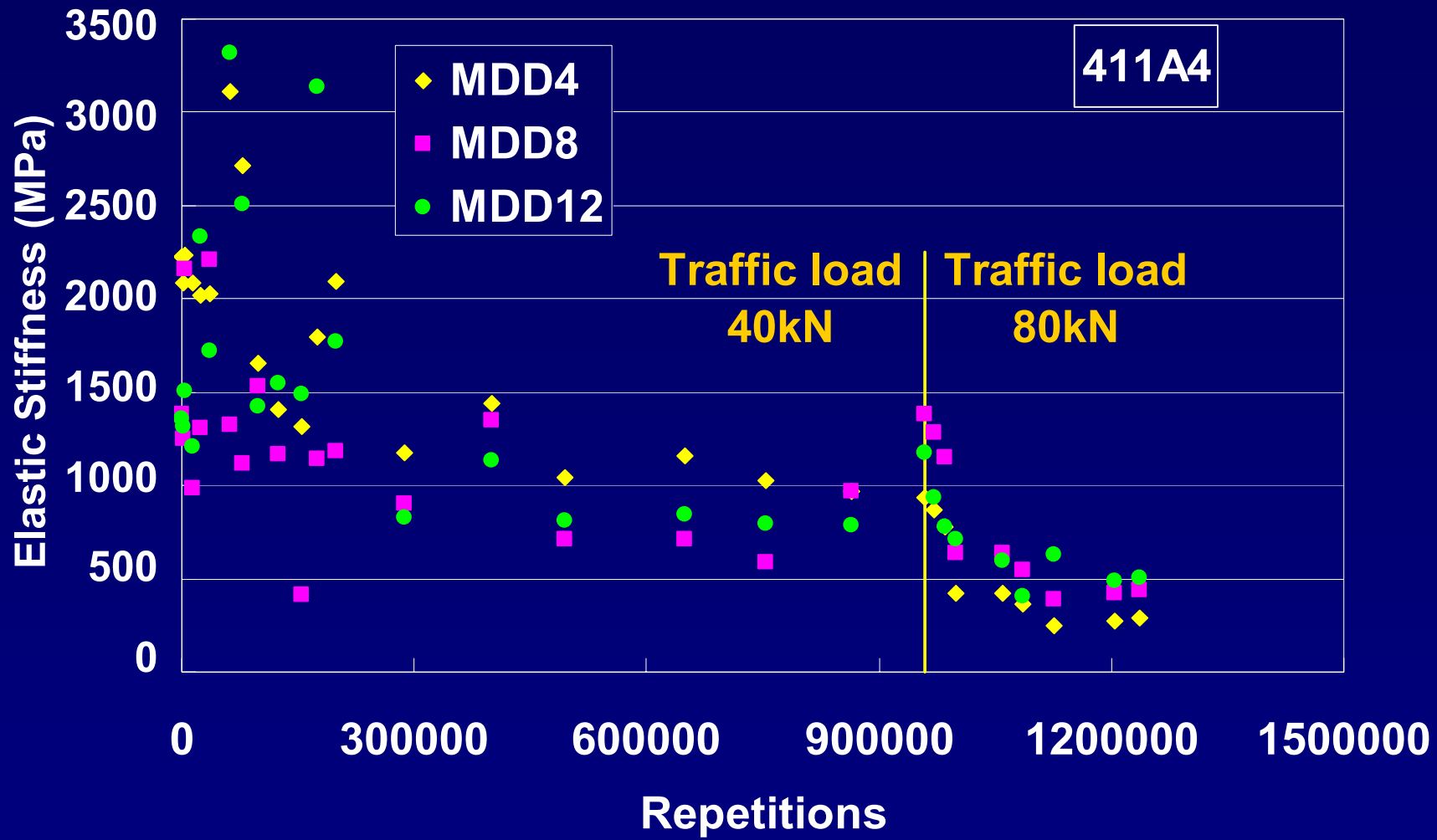
HVS test results: Depth deflection



HVS test results: M_r from MDD



HVS test results: M_r from MDD



HVS test conclusions

- AC Fatigue cracking
  - Initiated under high wheel-loads
  - Deteriorated during wet tests
  - Related to base stiffness
- Structural behaviour
  - Two components
    - » *Loss of stiffness: effective fatigue*
    - » *Permanent deformation*

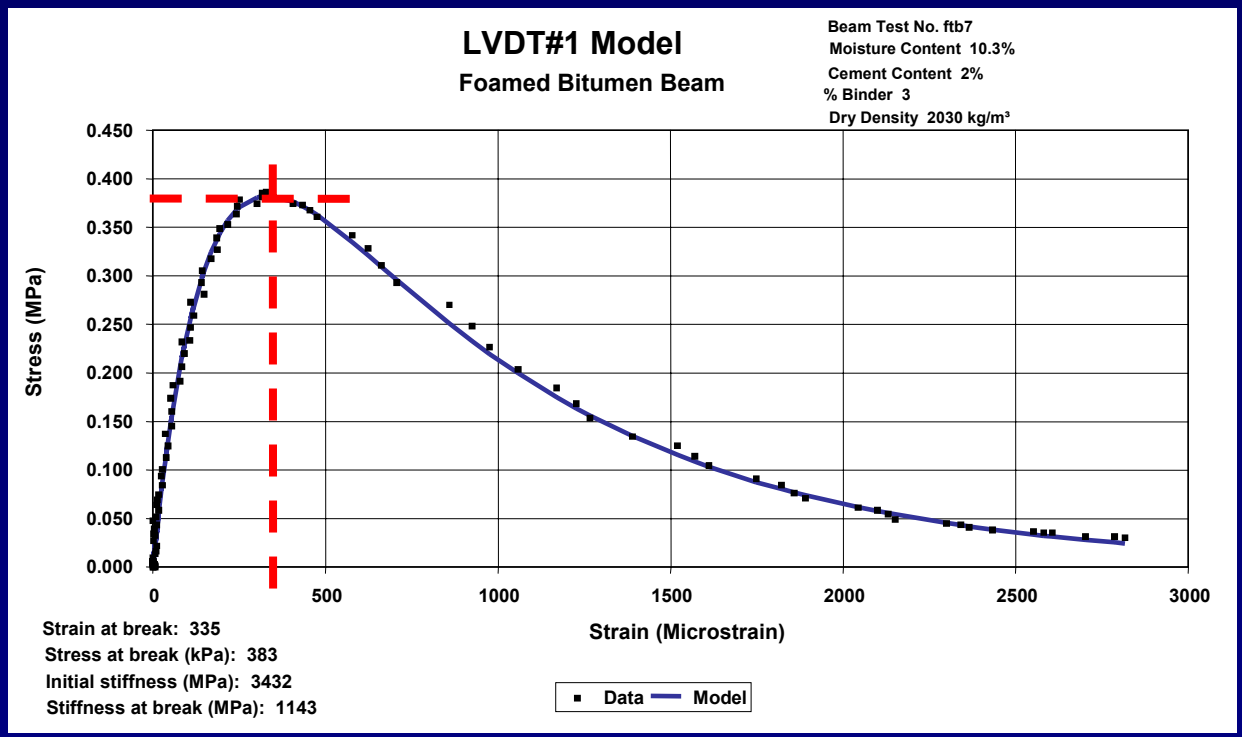
Laboratory testing

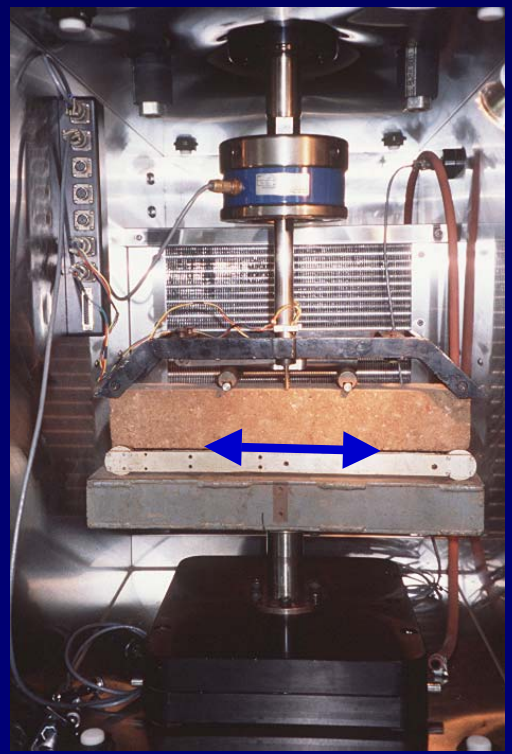
Performance characteristics

- Engineering parameters
  - Bearing strength (CBR)
  - Crushing strength (UCS)
  - Indirect tensile strength (ITS)
  - Erosion resistance
- Mechanical properties
  - Resilient modulus
  - Shear strength, maximum allowable principal stress
  - Tensile stress- and strain-at-break
- Structural capacity
  - Effective fatigue
  - Permanent deformation

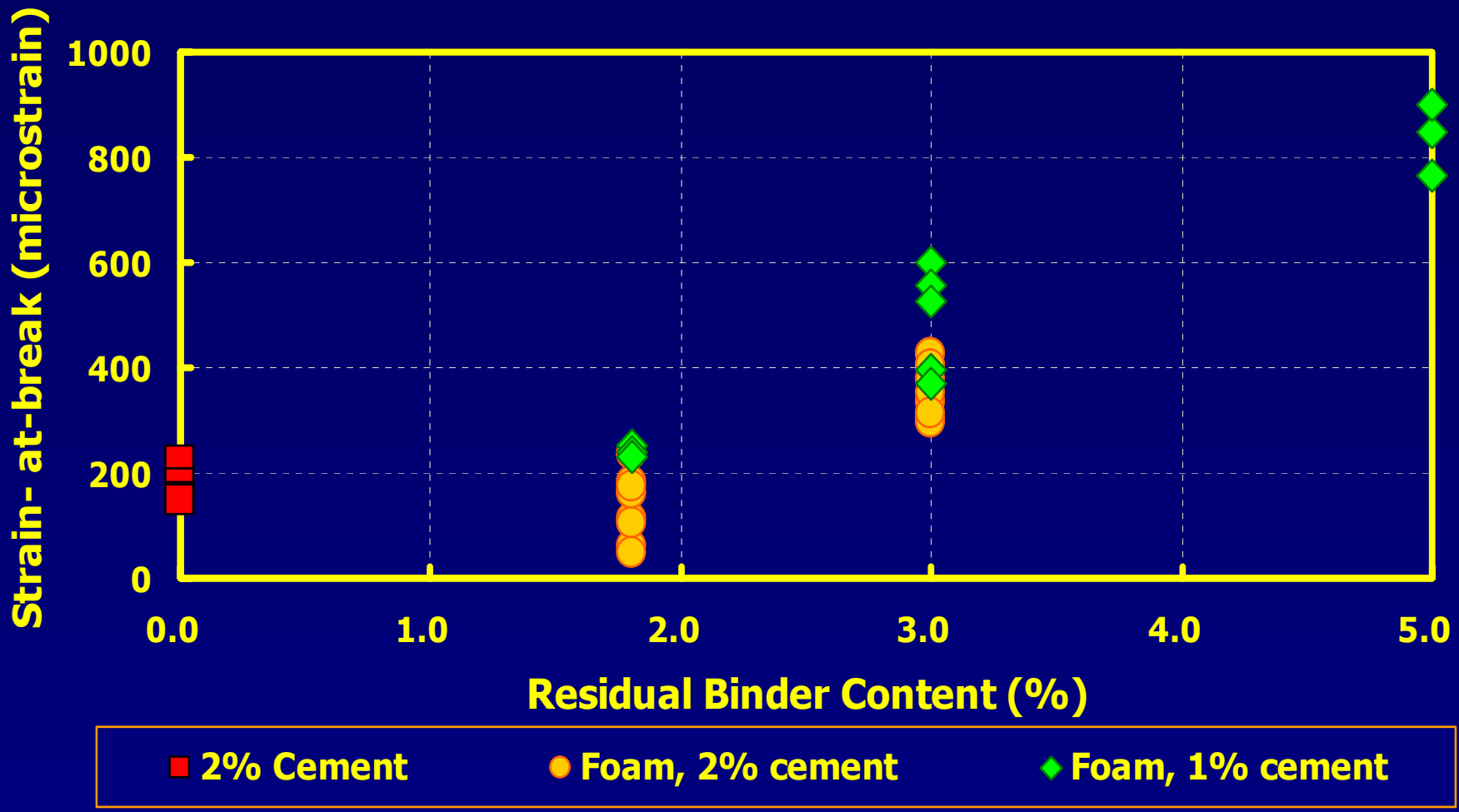
Flexural Beam Test

- Laboratory test
  - Four-point beam test
  - Strain-at-break, ε_b

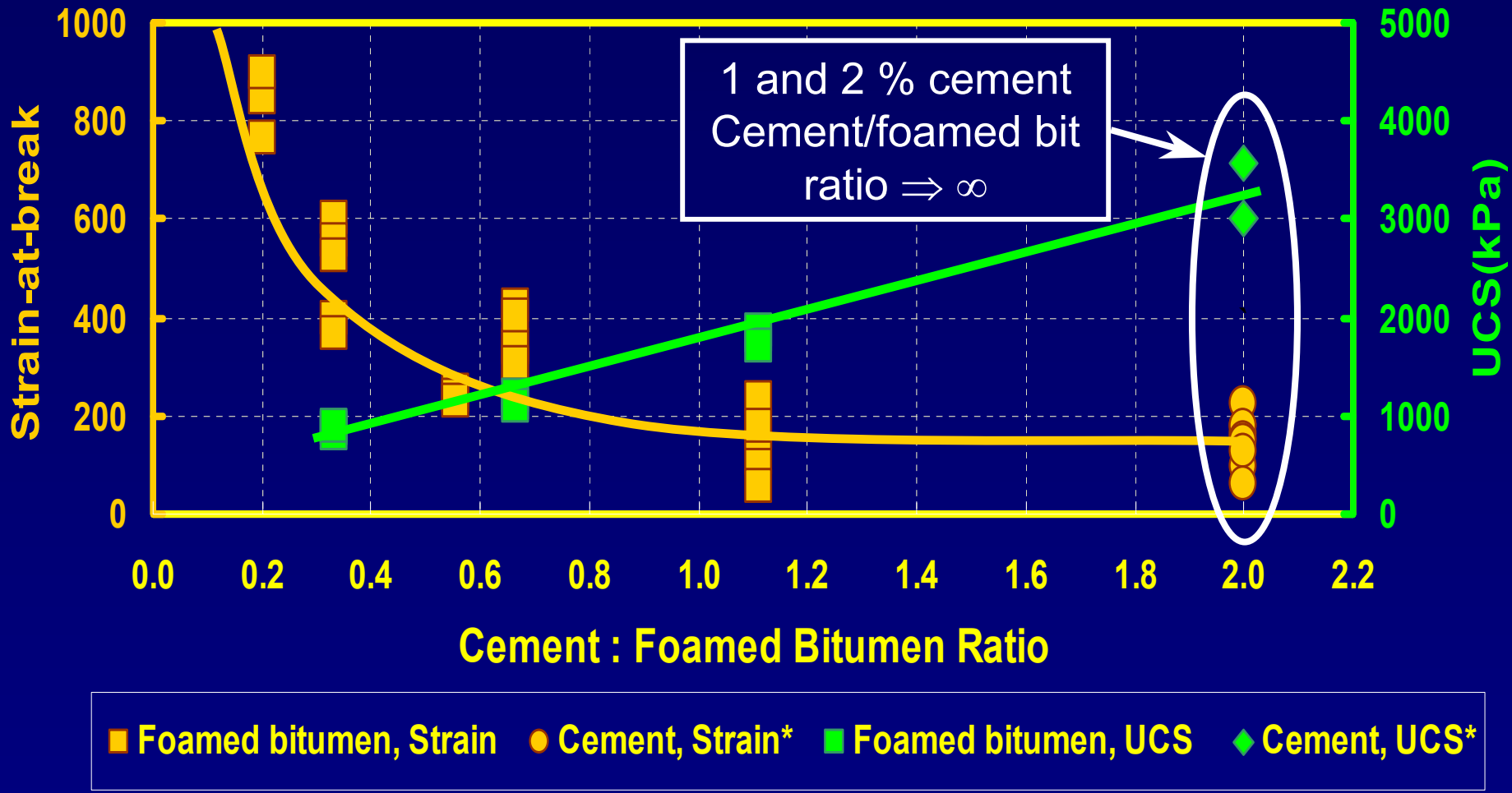




Laboratory test results: Strain-at-break

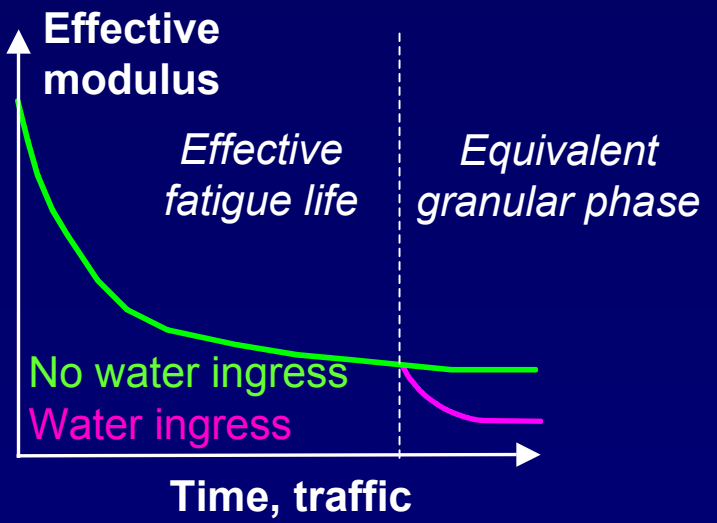


Laboratory test results: Strain-at-break/UCS



Behaviour of foamed bitumen treated materials

- High cohesive bonds initially
  - Effective fatigue life
- Bond destroyed by traffic action leading to reduction in modulus
- Equivalent granular phase
  - Permanent deformation



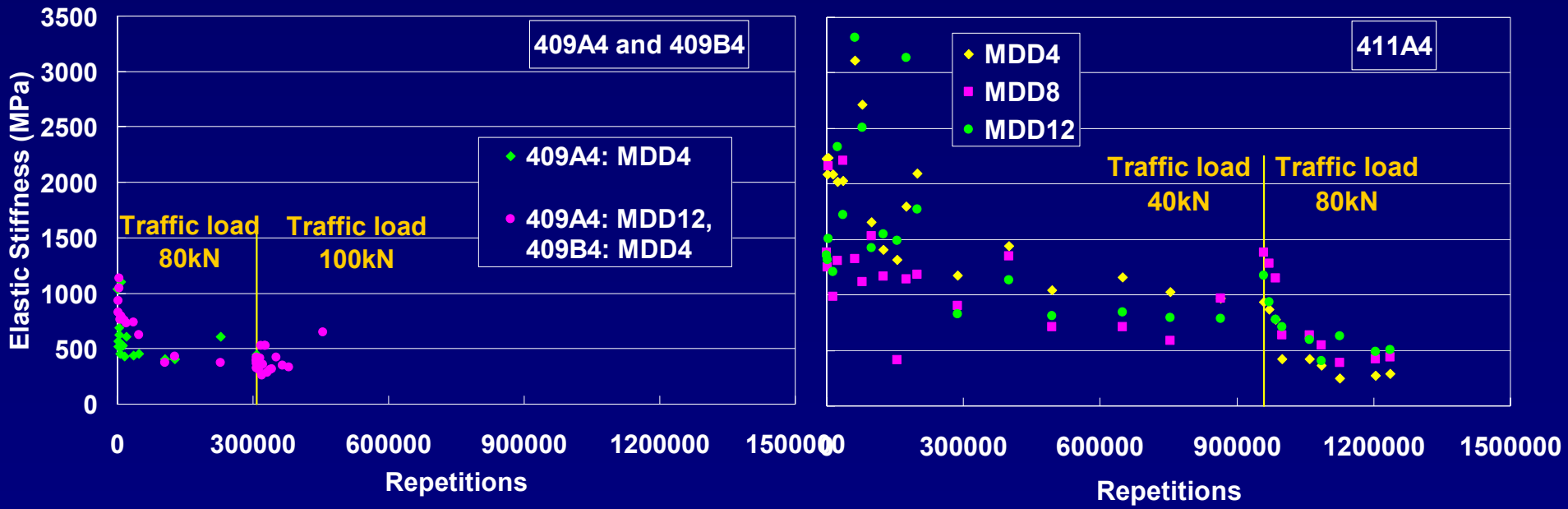
Effective fatigue transfer function

- Equivalent granular state
  - Loss in stiffness
  - Material not in loose condition of individual particles
  - Comparable to granular materials in stiffness only
    - » *not physical composition*
  - *NOT A TERMINAL CONDITION!*

- Results in
  - Less protection
  - Higher shear stresses in base
  - Increased horizontal strains in asphalt, increased fatigue

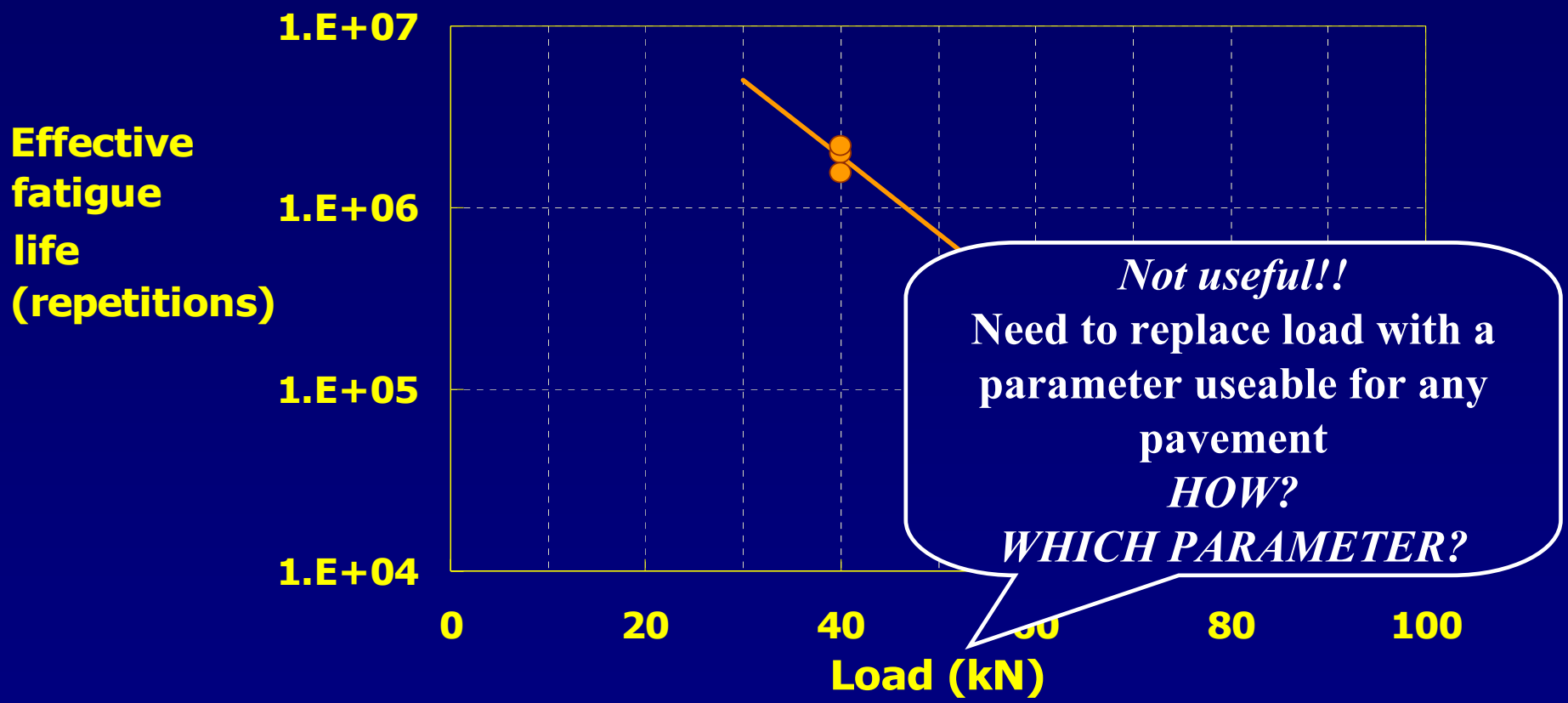
Effective fatigue transfer function

- HVS Tests
  - Reduction in stiffness
  - Equivalent granular state



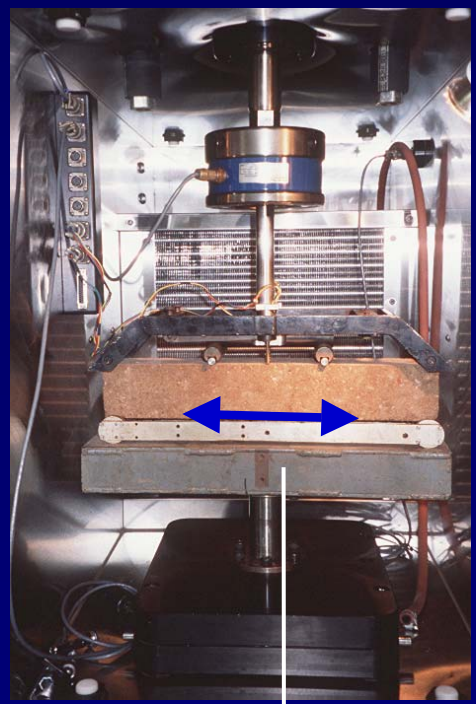
Effective fatigue transfer function

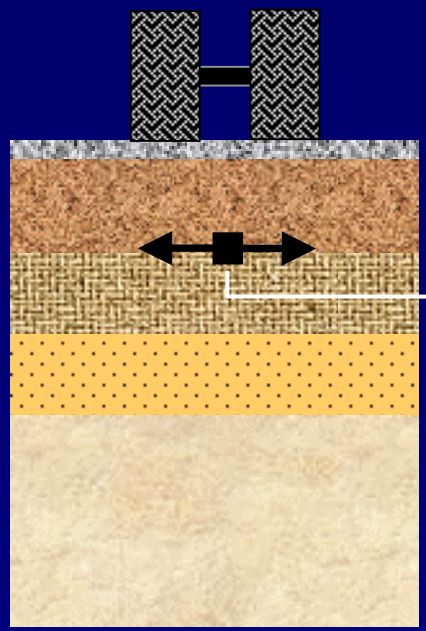
- Effective fatigue life
  - Repetitions to 400 MPa stiffness



Effective fatigue transfer function

- Strain ratio
  - Tensile strain at the bottom of the base, ε
    - » *Linear elastic analysis*
  - Strain-at-break from the laboratory test

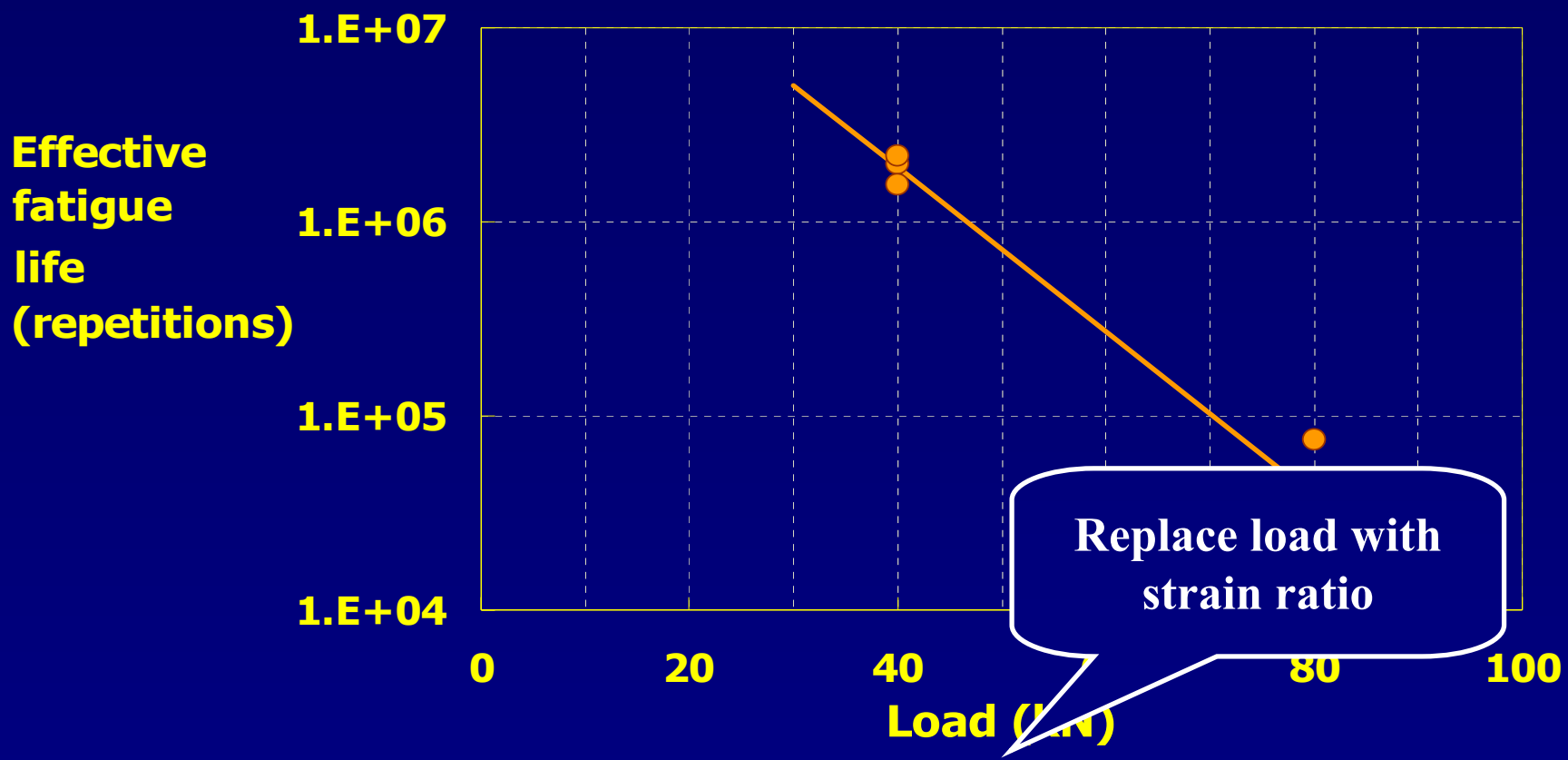




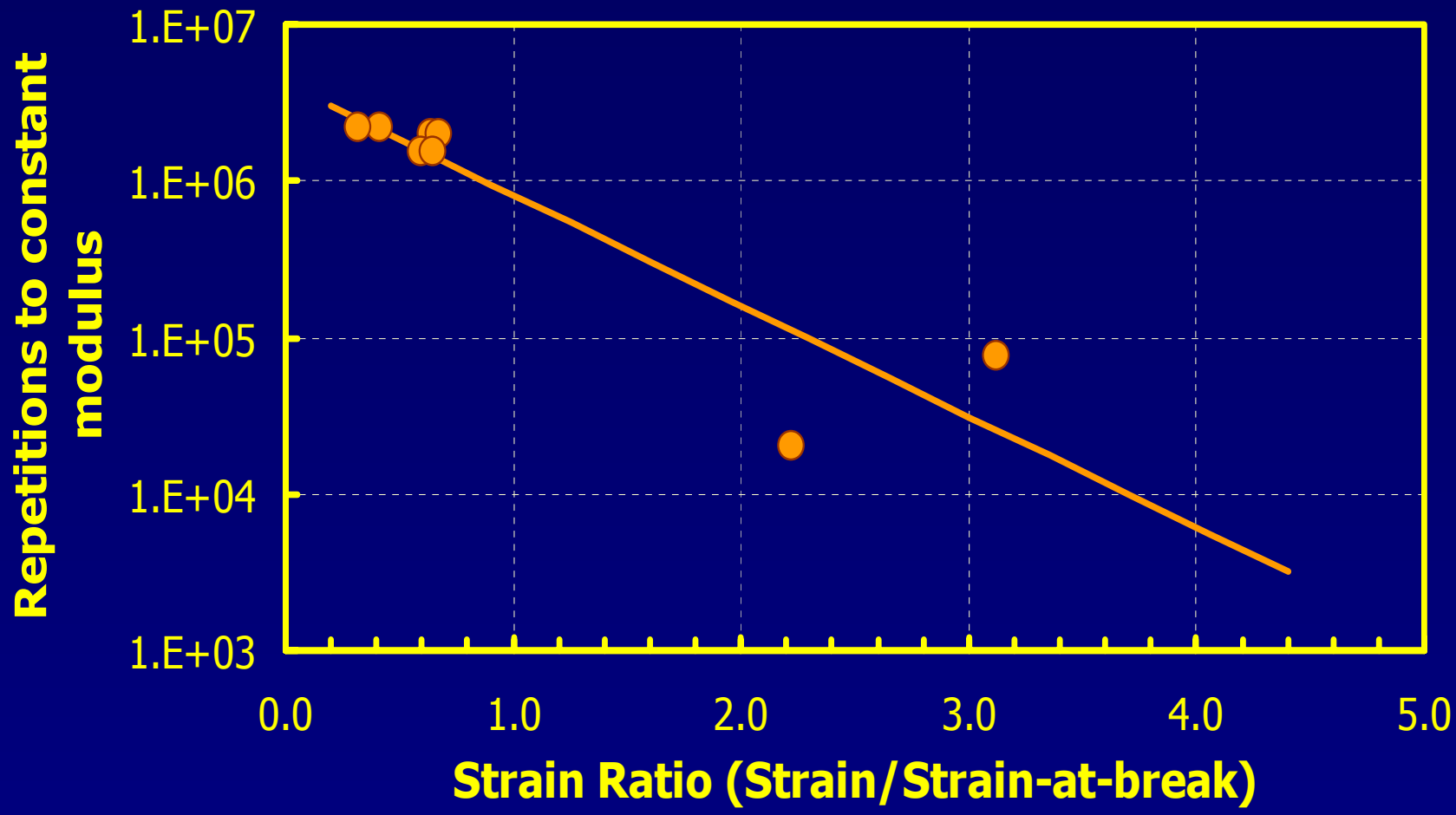
$$\text{Strain ratio} = \frac{\varepsilon}{\varepsilon_b}$$

Effective fatigue transfer function

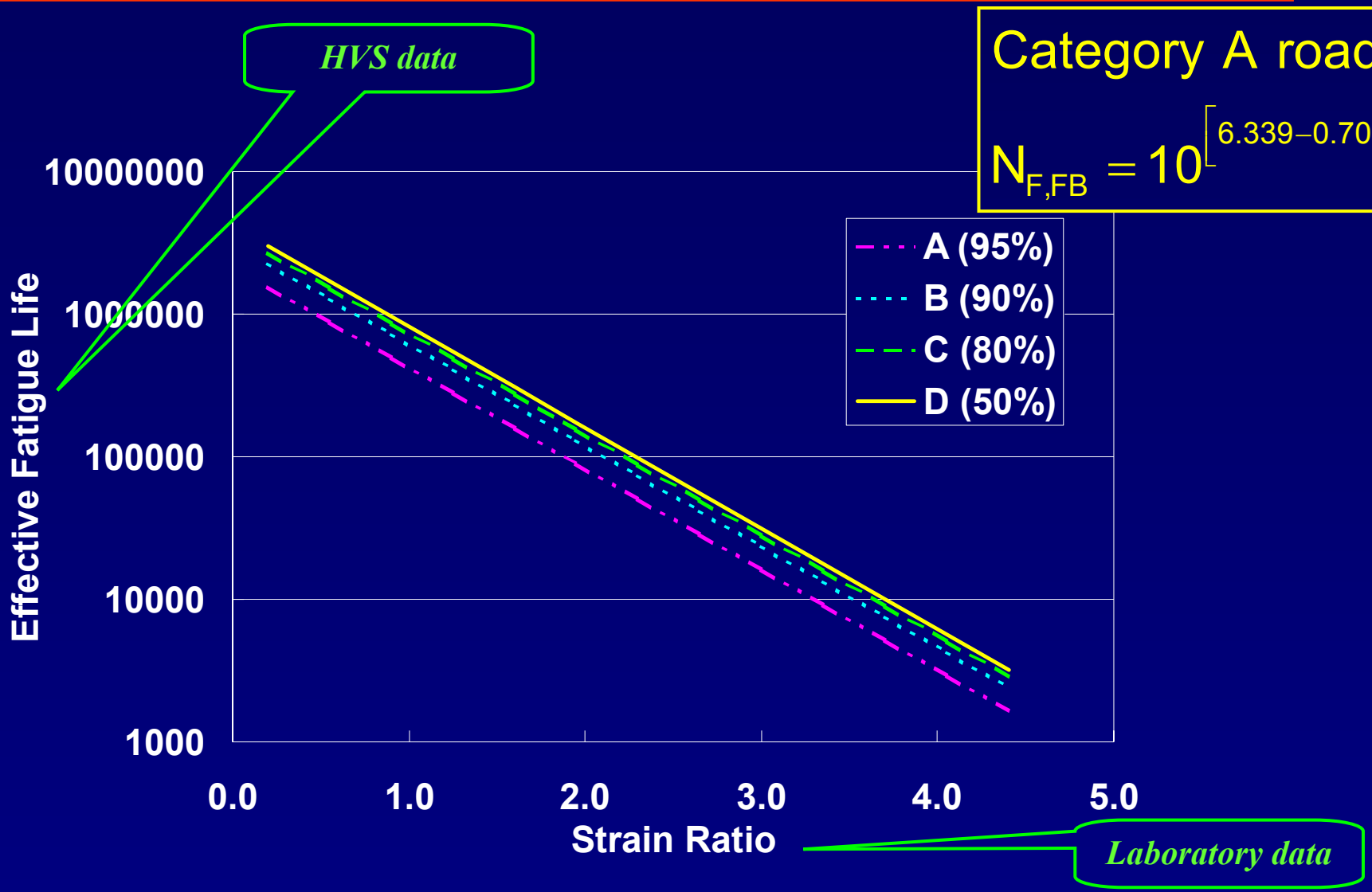
- Effective fatigue life
  - Repetitions to 400 MPa stiffness



Effective fatigue transfer function



Effective fatigue transfer function



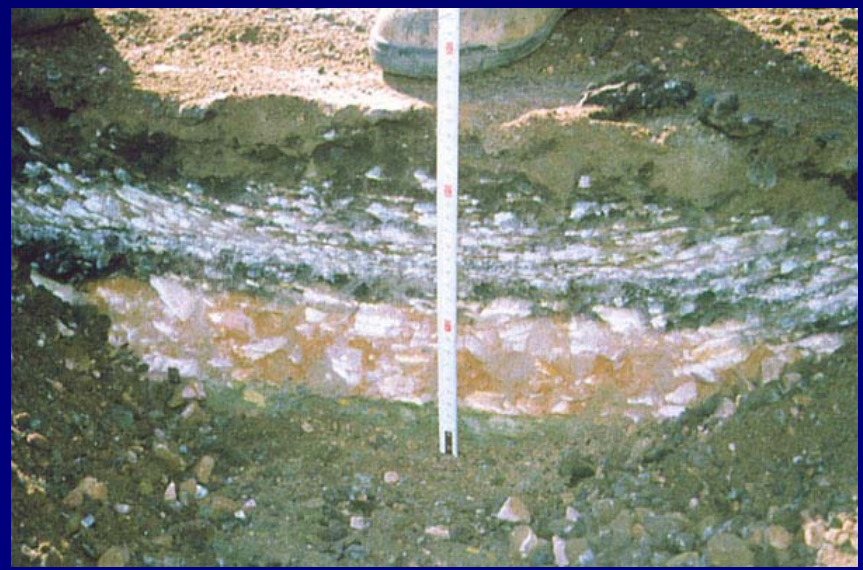
Effective fatigue transfer function

- Effective fatigue life is not a terminal condition
  - Layer continues to provide support in equivalent granular state
- Permanent deformation becomes dominant distress
- Pavement structural capacity
  - Effective fatigue life

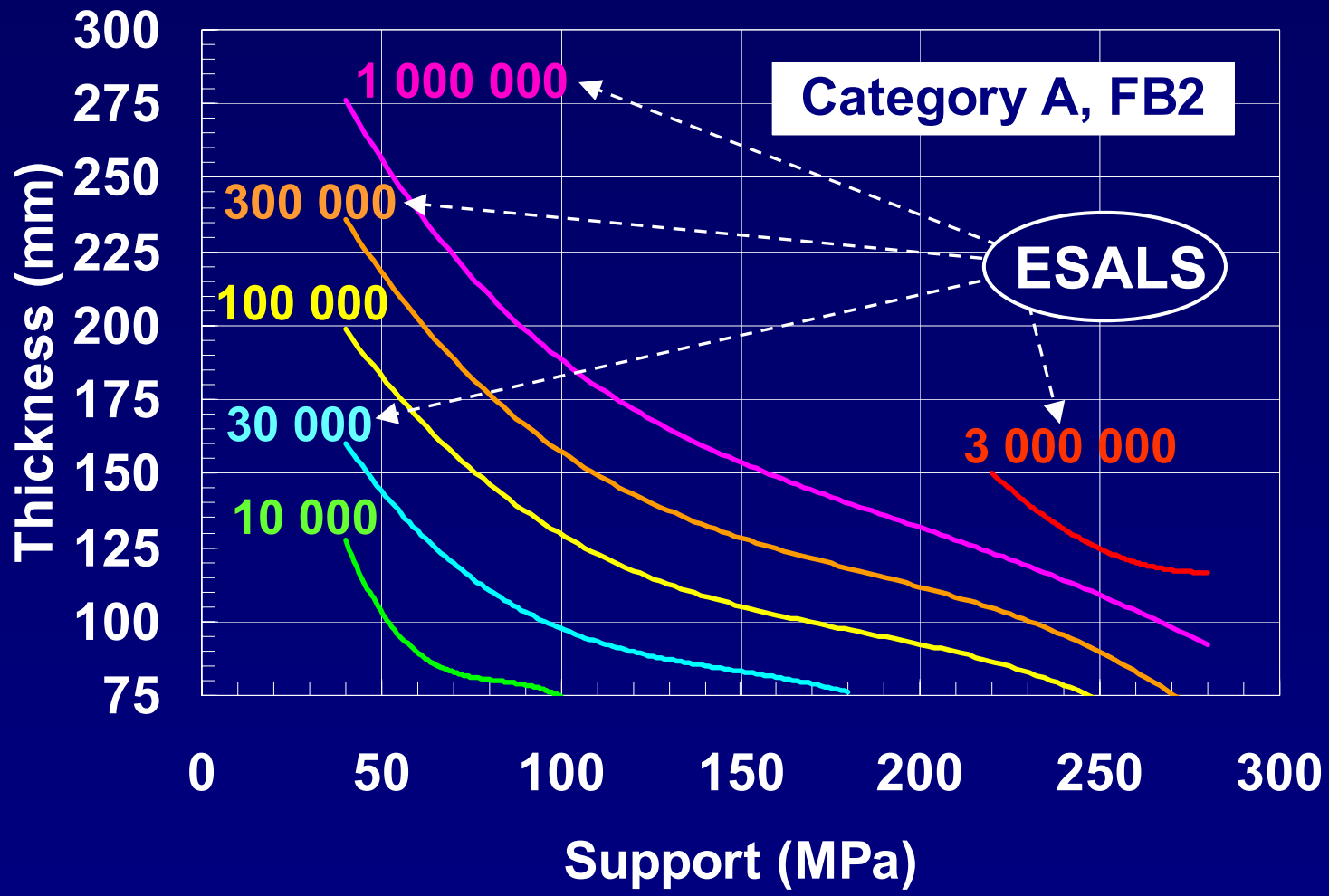
    AND
  - Permanent deformation life

Pavement design

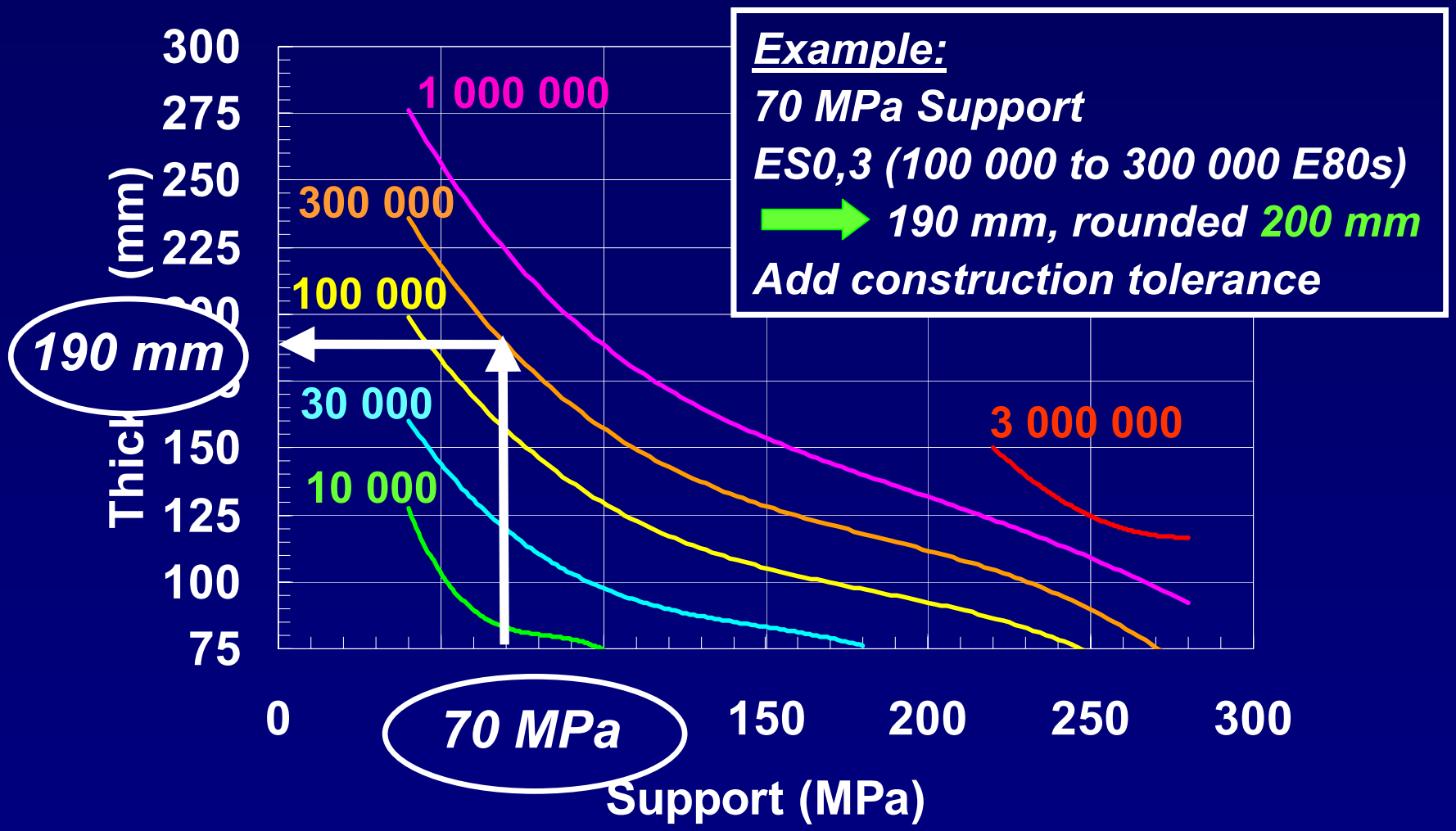
- Do full mechanistic-empirical design
  - Preferable
- Design charts
  - Developed using effective fatigue and permanent deformation transfer functions



Deep in situ reycling, design charts



Deep in situ reycling, design charts



Design catalogues and charts

- Minimum thickness, *do not* decrease
  - Add construction tolerance
- Designs assume routine maintenance performed

Conclusions

- Optimise cement:foamed bitumen content ratio
  - Increasing ratio
    - » *Improves strength*
    - » *Decreases flexibility*
- Combining HVS MDD and laboratory data obtained mechanistic-empirical structural design models for foamed bitumen
  - Two phases in pavement life
    - » *Effective fatigue*
    - » *Permanent deformation*

Conclusions

- Performance model from APT and laboratory
  - Laboratory
    - » *Fundamental understanding*
    - » *Wide range of variables*
  - HVS
    - » *Practical understanding*
    - » *Calibration for full-scale boundary conditions*
    - » *MDD depth data essential*

Questions??