# Modify and Expand the Concrete Pavement Design Method, cncPAVE to Include Block Pavement Design and to add it into the SAPDM

# TASKS

The further development and refinement of cncPAVE including the following:

1. Load transfer model for cracks and joints to include the effect of steel fibre reinforcement
2. Riding quality deterioration models based on IRI
3. Interaction between the concrete slab and the subbase with special reference to erosion of this layer
4. Incorporate a mechanistic-empirical design method for block paving into cncPAVE
5. Integration of cncPAVE into the SAPDM system.

# 1. Load transfer model for cracks and joints

The extent to which a load can be transferred from one slab to the adjoining slab depends on:

- The crack/joint width, thus shrinkage, crack/joint spacing etc.
- Non-uniformity in the joint/crack thus concrete mix properties, aggregate size, ACV
- Reinforcement/dowels/steel fibres that may traverse the crack/joint
- The magnitude and number of traffic loads at a joint/crack

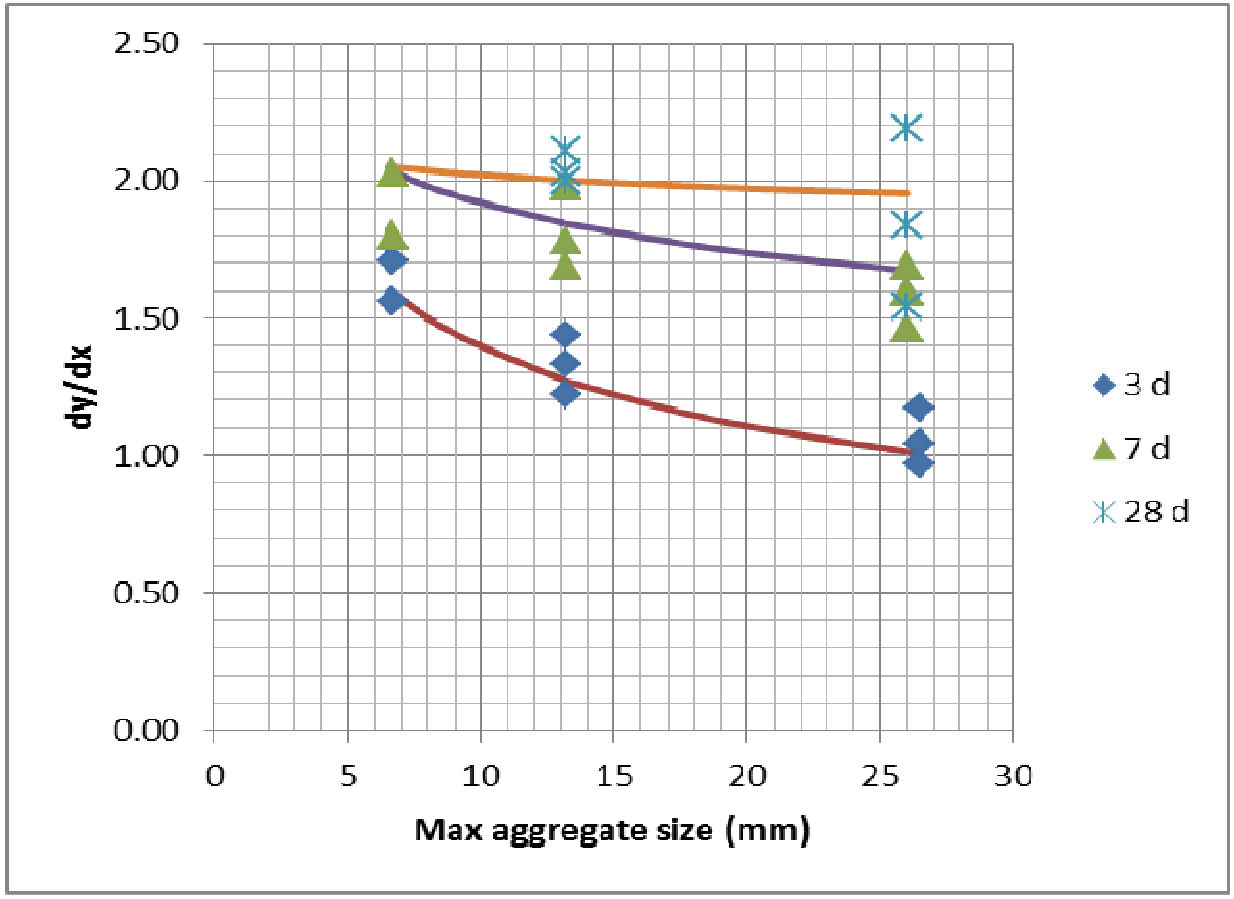
# Quantify the magnitude of load transferred at a crack or joint

Manufacture beams using different concrete mixes and fibre contents. Test the following:

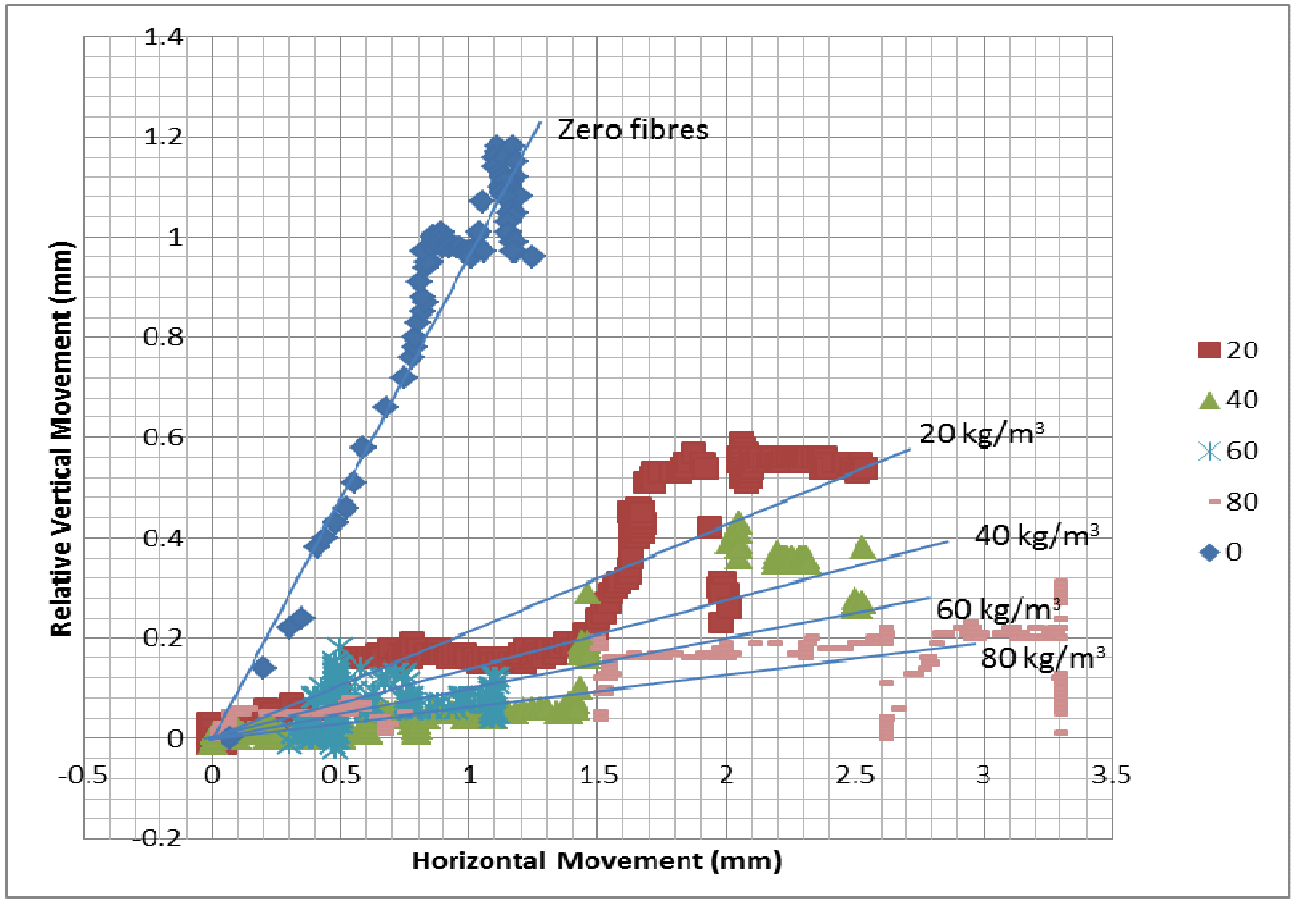
- First set of beams: Measure flexural strength at different ages
- Second set of beams: Just initiate a crack and then vary the crack width and measure the movement across the crack at different loads

# Laboratory Testing

# Results so far: Aggregate size



# Results so far: Fibre Content



# 2. Pavement Distress and International Roughness Index (IRI)

IRI measured using instruments and used to determine road users cost and pavement performance. It therefore depends on:

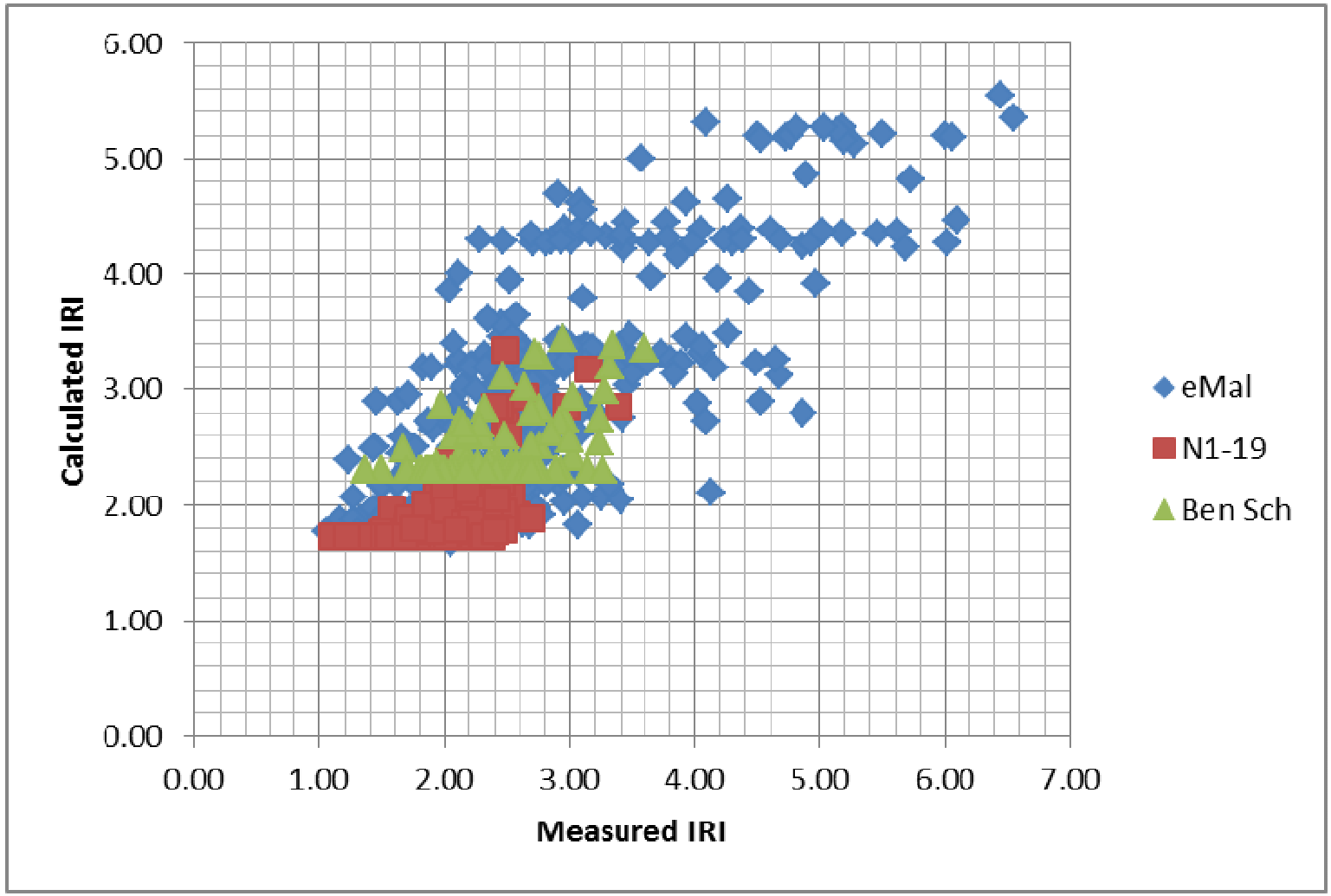
- Initial roughness after construction
- Shattered slabs
- Faulting at joins/cracks
- Repairs

# Evaluation of IRI versus Distress

Many concrete sections have been rehabilitated after distress but the following was very useful:

- N1/19 : JCP south of Johannesburg
(Vaal River to Misgund)
- N4/3: JCP east of eMalahleni
(Witbank to Middelburg)
- N1/19 & 20: CRCP Pretoria to Johannesburg
(Ben Schoeman highway)

# Linear plot of Adjusted Data



# Prediction

IRI = f(Initial IRI, Area shattered,
area repaired, faulting at joints)

# 3. Erosion of the subbase

- The performance of a concrete slab depends to a great extent on slab support
- High deflection, subbase with low stiffness and water cause erosion (pumping)
- Brush test being used to quantify erodibility
- A factor (constant) is presently being used
- Investigate use of the Rotational Shear Device to enable a mechanistic approach


Torque Transducer
Stabilising Arm
Thrust Bearing
Top Disk
Sample
Rotating Cylinder
Bottom Disk

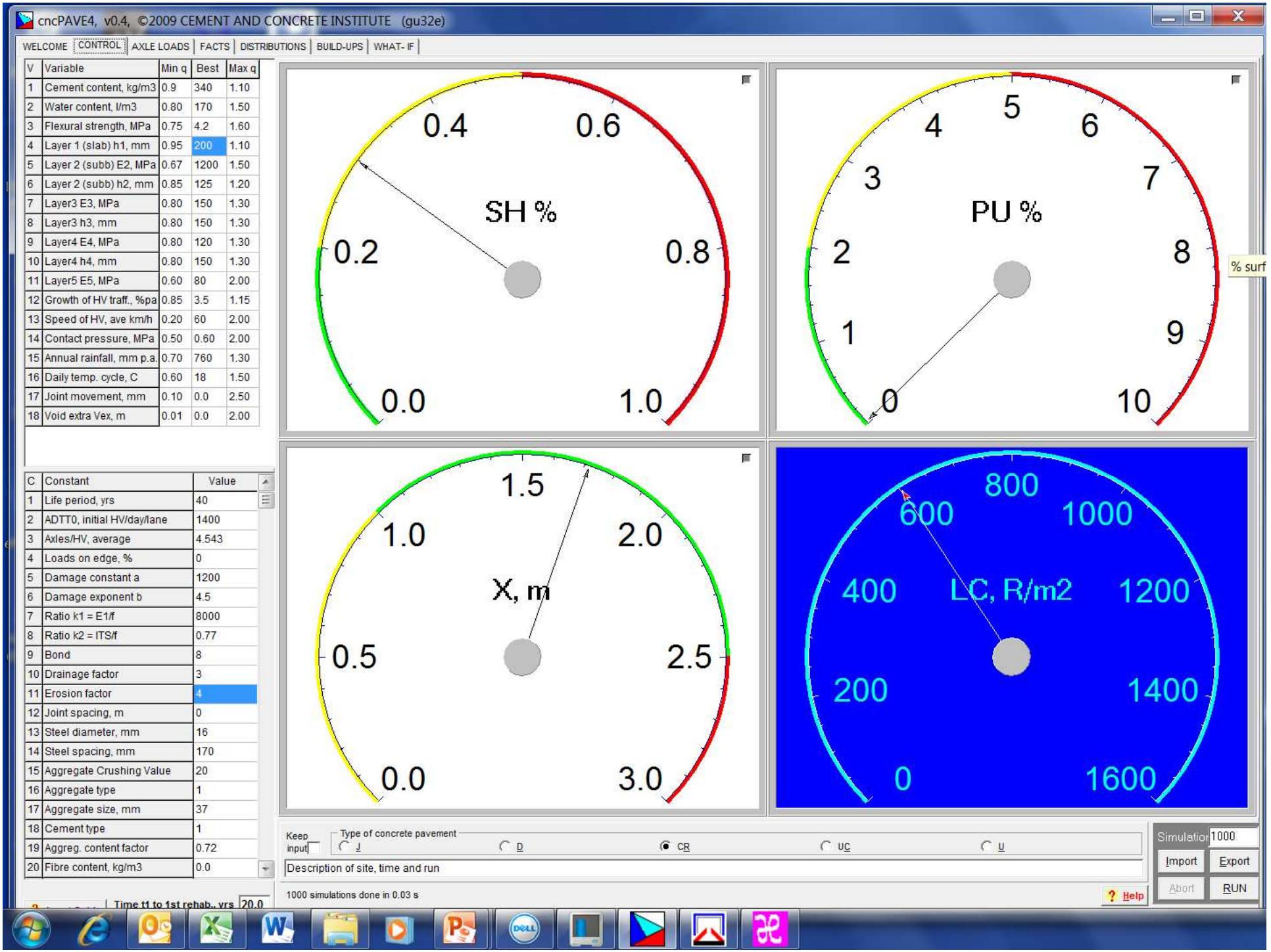
# Test Method Considered at this Time

- Sample, 100mm diameter and 100mm high prepared using standard lab procedures
- Rotate at 1500 rpm for between 0.5 and 2 hours
- Material's loss to be between 0 and 10% depending on resistance to erosion
- Hopefully stripping of bituminous layer below slab can also be determined

# 4. Adding the Design of Interlocking Block Pavements

Use the same page layout as being used in cncPAVE:

- Control page for input of variables and constants
- Traffic load page with typical distributions and the capability to use real data obtained
- Facts page showing the detailed outcome of a run
- Pages showing typical distribution and changes with time of the more important output
- What-if to plot the outcome as a function of different input parameters.


cncPAVE4, v0.4, ©2009 CEMENT AND CONCRETE INSTITUTE (gu32e)
WELCOME
CONTROL
AXLE LOADS
FACTS
DISTRIBUTIONS
BUILD-UPS
WHAT- IF
V | Variable | Min q | Best | Max q
1 | Cement content, kg/m3 | 0.9 | 340 | 1.10
2 | Water content, l/m3 | 0.80 | 170 | 1.50
3 | Flexural strength, MPa | 0.75 | 4.2 | 1.60
4 | Layer 1 (slab) h1, mm | 0.95 | 200 | 1.10
5 | Layer 2 (subb) E2, MPa | 0.67 | 1200 | 1.50
6 | Layer 2 (subb) h2, mm | 0.85 | 125 | 1.20
7 | Layer3 E3, MPa | 0.80 | 150 | 1.30
8 | Layer3 h3, mm | 0.80 | 150 | 1.30
9 | Layer4 E4, MPa | 0.80 | 120 | 1.30
10 | Layer4 h4, mm | 0.80 | 150 | 1.30
11 | Layer5 E5, MPa | 0.60 | 80 | 2.00
12 | Growth of HV traff., %pa | 0.85 | 3.5 | 1.15
13 | Speed of HV, ave km/h | 0.20 | 60 | 2.00
14 | Contact pressure, MPa | 0.50 | 0.60 | 2.00
15 | Annual rainfall, mm p.a. | 0.70 | 760 | 1.30
16 | Daily temp. cycle, C | 0.60 | 18 | 1.50
17 | Joint movement, mm | 0.10 | 0.0 | 2.50
18 | Void extra Vex, m | 0.01 | 0.0 | 2.00
C | Constant | Value
1 | Life period, yrs | 40
2 | ADTT0, initial HV/day/lane | 1400
3 | Axles/HV, average | 4.543
4 | Loads on edge, % | 0
5 | Damage constant a | 1200
6 | Damage exponent b | 4.5
7 | Ratio k1 = E1/f | 8000
8 | Ratio k2 = ITS/f | 0.77
9 | Bond | 8
10 | Drainage factor | 3
11 | Erosion factor | 4
12 | Joint spacing, m | 0
13 | Steel diameter, mm | 16
14 | Steel spacing, mm | 170
15 | Aggregate Crushing Value | 20
16 | Aggregate type | 1
17 | Aggregate size, mm | 37
18 | Cement type | 1
19 | Aggreg. content factor | 0.72
20 | Fibre content, kg/m3 | 0.0
Time t1 to 1st rehab., yrs
20.0
0.4
0.6
SH %
0.2
0.8
0.0
1.0
5
4
6
3
7
PU %
2
8
% surf
1
9
0
10
1.5
1.0
2.0
X, m
0.5
2.5
0.0
3.0
800
600
1000
400
LC, R/m2
1200
200
1400
0
1600
Keep input
Type of concrete pavement
J
D
CR
UC
U
Description of site, time and run
1000 simulations done in 0.03 s
Help
Simulation
1000
Import
Export
Abort
RUN

cncPAVE4, v0.4, ©2009 CEMENT AND CONCRETE INSTITUTE (gu32e)

WELCOME | CONTROL | AXLE LOADS | FACTS | DISTRIBUTIONS | BUILD-UPS | WHAT- IF

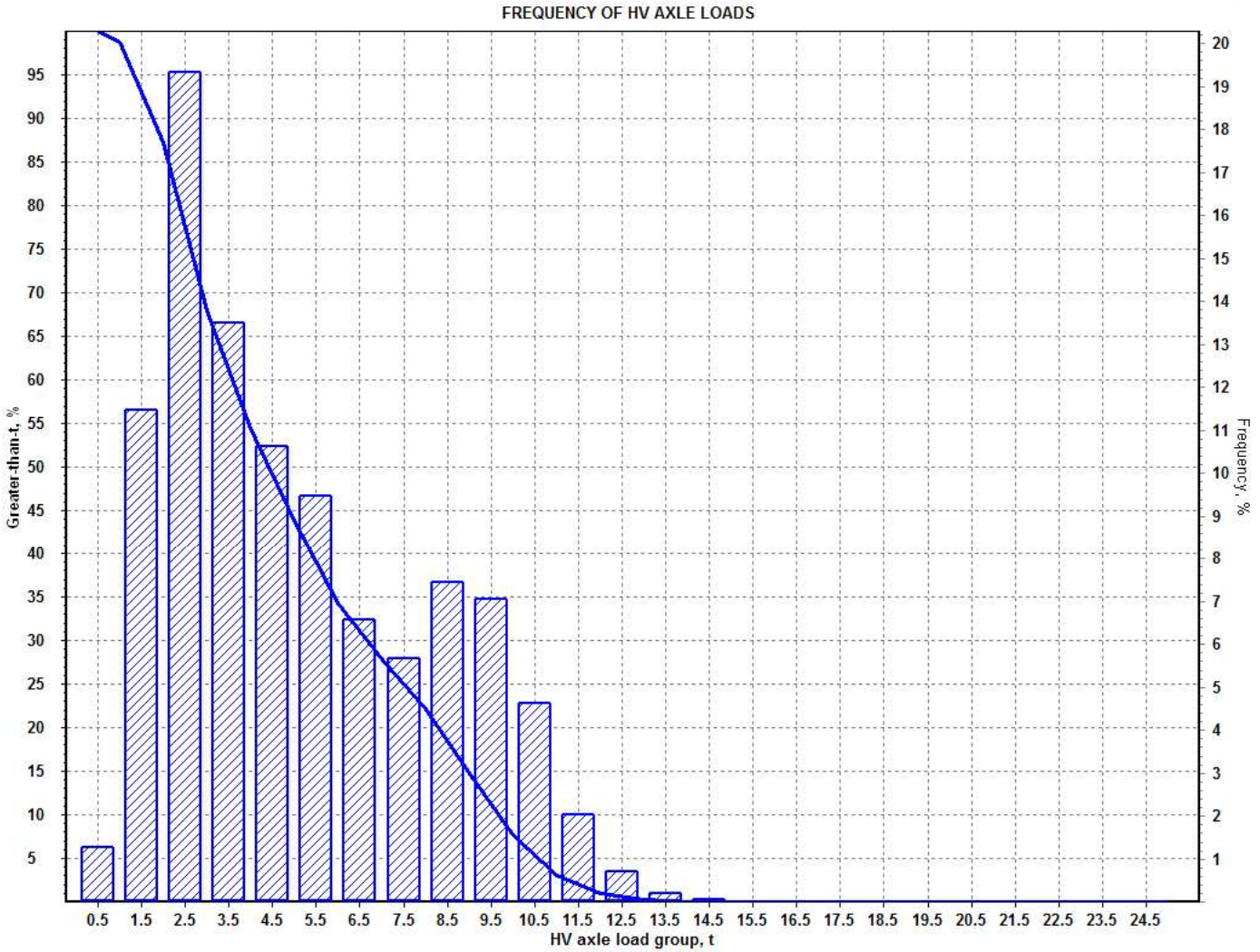
TRAFFIC SITUATION

- T1: %LongHV < 35; (Any LE*)
- (•) T2: %LongHV 35-55; Weak LE
- T3: %LongHV 35-55; Strong LE
- T4: %LongHV > 55; Weak LE
- T5: %LongHV > 55; Strong LE
- Streets in heavy-industry areas
- Streets in light-industry areas
- Residential streets
- Heavy-truck standing areas
- Light-truck standing areas
- One single axle load
- Other traffic situation

| Load, t | Freq, % |
|---|---|
| 0.5000 | 1.27 |
| 1.5000 | 11.46 |
| 2.5000 | 19.32 |
| 3.5000 | 13.50 |
| 4.5000 | 10.63 |
| 5.5000 | 9.48 |
| 6.5000 | 6.56 |
| 7.5000 | 5.66 |
| 8.5000 | 7.45 |
| 9.5000 | 7.05 |
| 10.5000 | 4.61 |
| 11.5000 | 2.04 |
| 12.5000 | 0.70 |
| 13.5000 | 0.21 |
| 14.5000 | 0.06 |
| 15.5000 | 0.00 |
| 16.5000 | 0.00 |
| 17.5000 | 0.00 |

k-factor 1.000

Print ...




* LE is 'law enforcement against overloading'

Traffic growth (•) Lin ( ) Exp

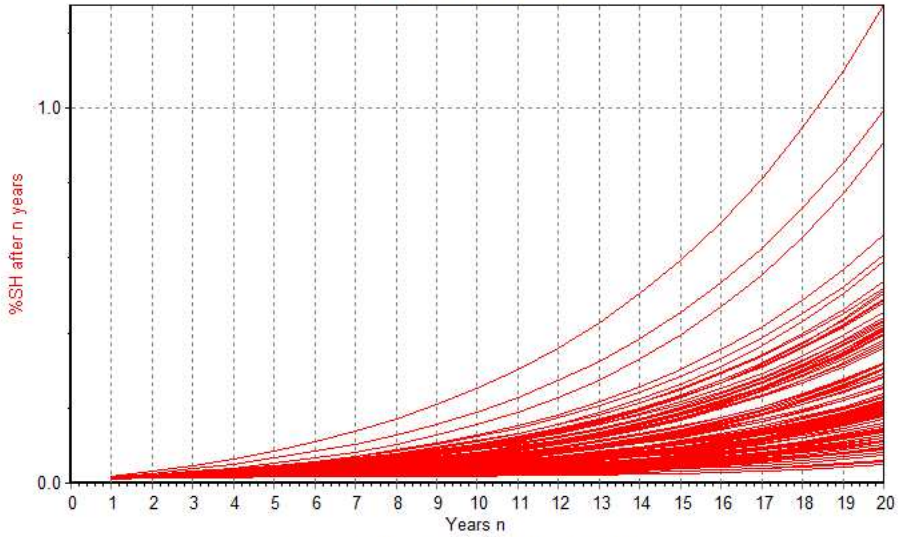
Unpack | Normalize | Help

cncPAVE4, v0.4, ©2009 CEMENT AND CONCRETE INSTITUTE (gu32e)

WELCOME | CONTROL | AXLE LOADS | FACTS | DISTRIBUTIONS | BUILD-UPS | WHAT- IF

Print ...

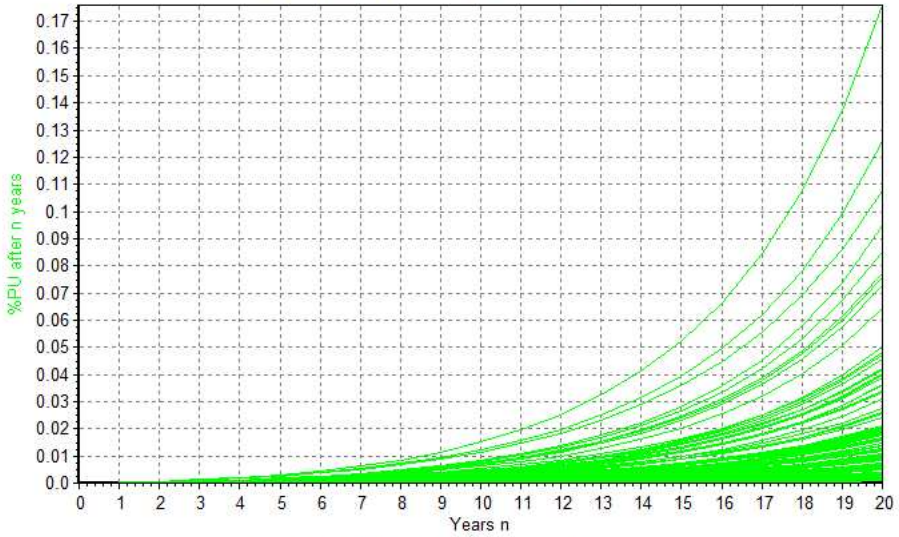
SURFACE WITH SHATTERED CONCRETE




*Description of site, time and run v0.4 gu 28/10/11*

Print ...

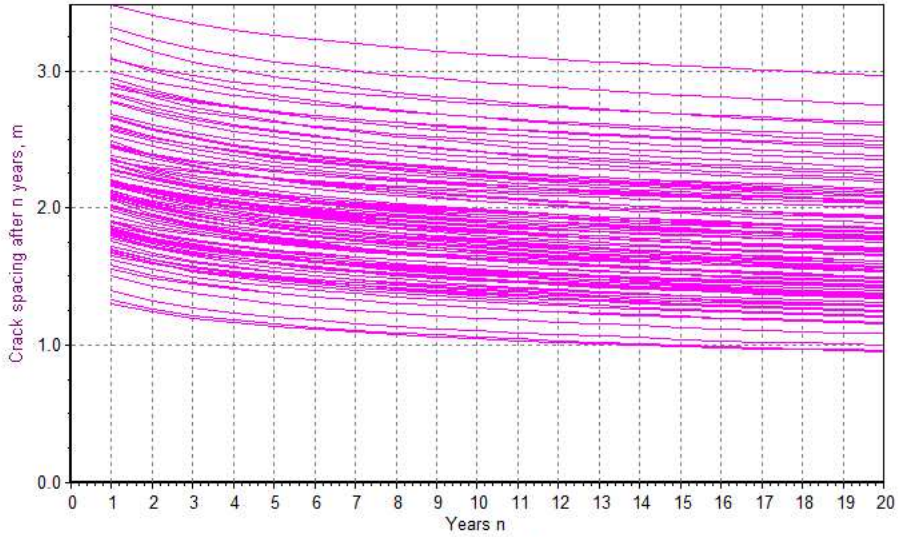
PERCENTAGE OF SURFACE AREA PUMPING




*Description of site, time and run v0.4 gu 28/10/11*

Print ...

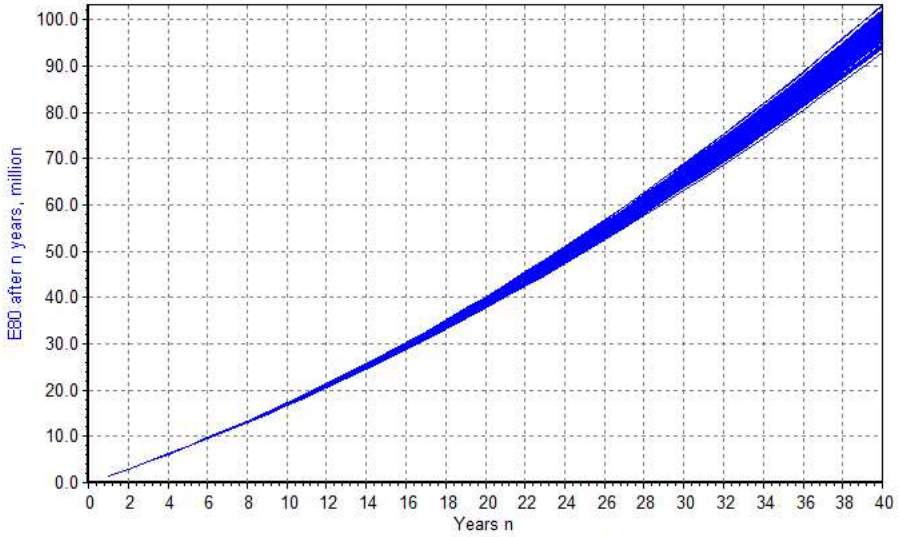
CRACK SPACING DUE TO SHRINKAGE




*Description of site, time and run v0.4 gu 28/10/11*

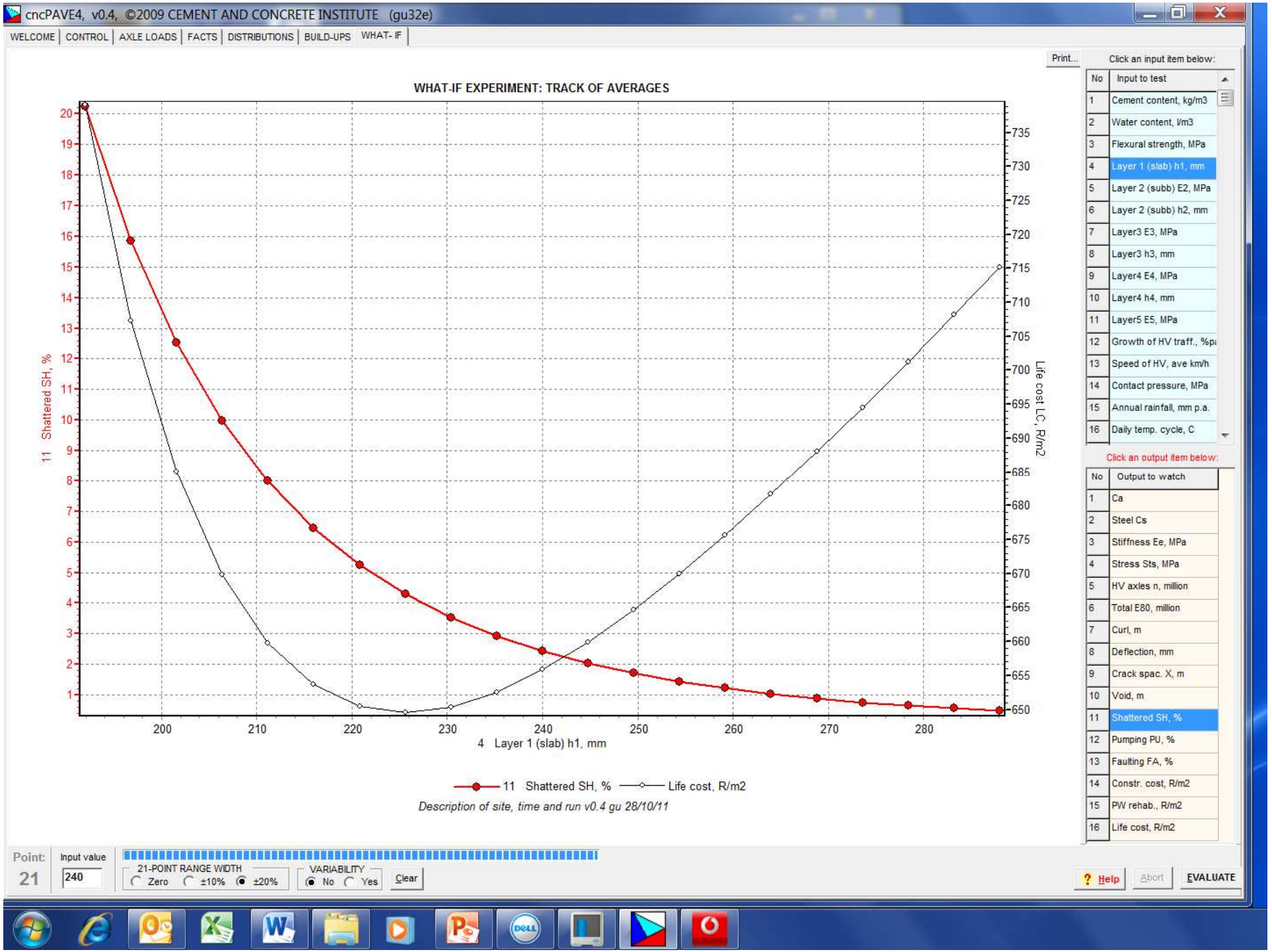
Print ...

BUILD-UP OF E80 OVER LIFE PERIOD




*Description of site, time and run v0.4 gu 28/10/11*

Help


cncPAVE4, v0.4, ©2009 CEMENT AND CONCRETE INSTITUTE (gu32e)
WELCOME | CONTROL | AXLE LOADS | FACTS | DISTRIBUTIONS | BUILD-UPS | WHAT- IF
Print...
WHAT-IF EXPERIMENT: TRACK OF AVERAGES
11 Shattered SH, %
Life cost LC, R/m2
4 Layer 1 (slab) h1, mm
11 Shattered SH, %
Life cost, R/m2
Description of site, time and run v0.4 gu 28/10/11
Click an input item below:
No
Input to test
1 Cement content, kg/m3
2 Water content, l/m3
3 Flexural strength, MPa
4 Layer 1 (slab) h1, mm
5 Layer 2 (subb) E2, MPa
6 Layer 2 (subb) h2, mm
7 Layer3 E3, MPa
8 Layer3 h3, mm
9 Layer4 E4, MPa
10 Layer4 h4, mm
11 Layer5 E5, MPa
12 Growth of HV traff., %p
13 Speed of HV, ave km/h
14 Contact pressure, MPa
15 Annual rainfall, mm p.a.
16 Daily temp. cycle, C
Click an output item below:
No
Output to watch
1 Ca
2 Steel Cs
3 Stiffness Ee, MPa
4 Stress Sts, MPa
5 HV axles n, million
6 Total E80, million
7 Curl, m
8 Deflection, mm
9 Crack spac. X, m
10 Void, m
11 Shattered SH, %
12 Pumping PU, %
13 Faulting FA, %
14 Constr. cost, R/m2
15 PW rehab., R/m2
16 Life cost, R/m2
Point:
21
Input value
240
21-POINT RANGE WIDTH
Zero ±10% ±20%
VARIABILITY
No Yes
Clear
Help
Abort
EVALUATE

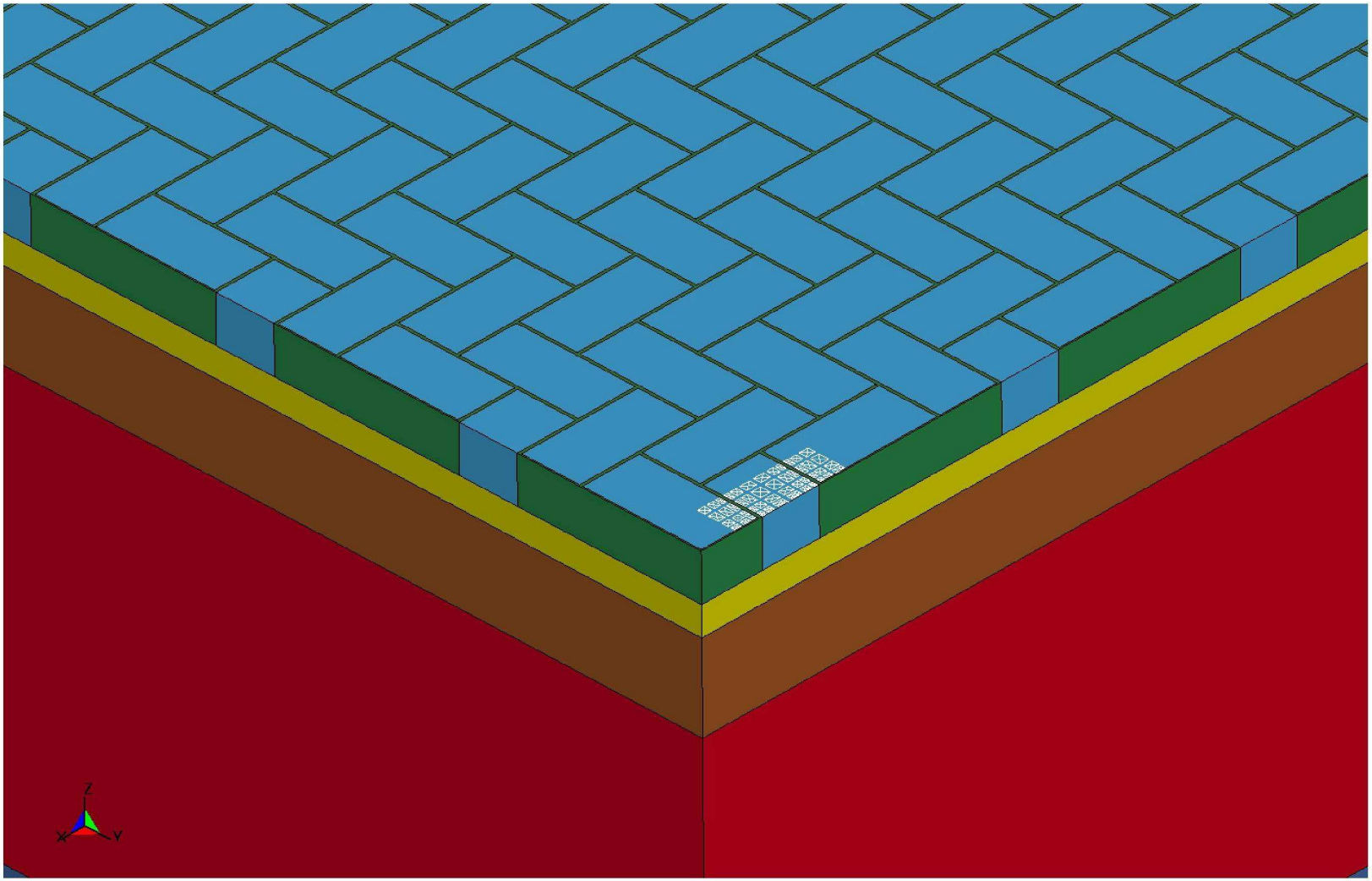
# Development

Block pavement divided into two components:

- The paving blocks with sand filled joints placed on top of a bedding sand about 30mm thick. Finite element analysis the best tool.
- The subbase and lower layers below the bedding sand. Normal multi-layer analyses can be used in this case. Ties in with approach used in flexible pavement design.


21.06.2011

# 3-D Finite element model

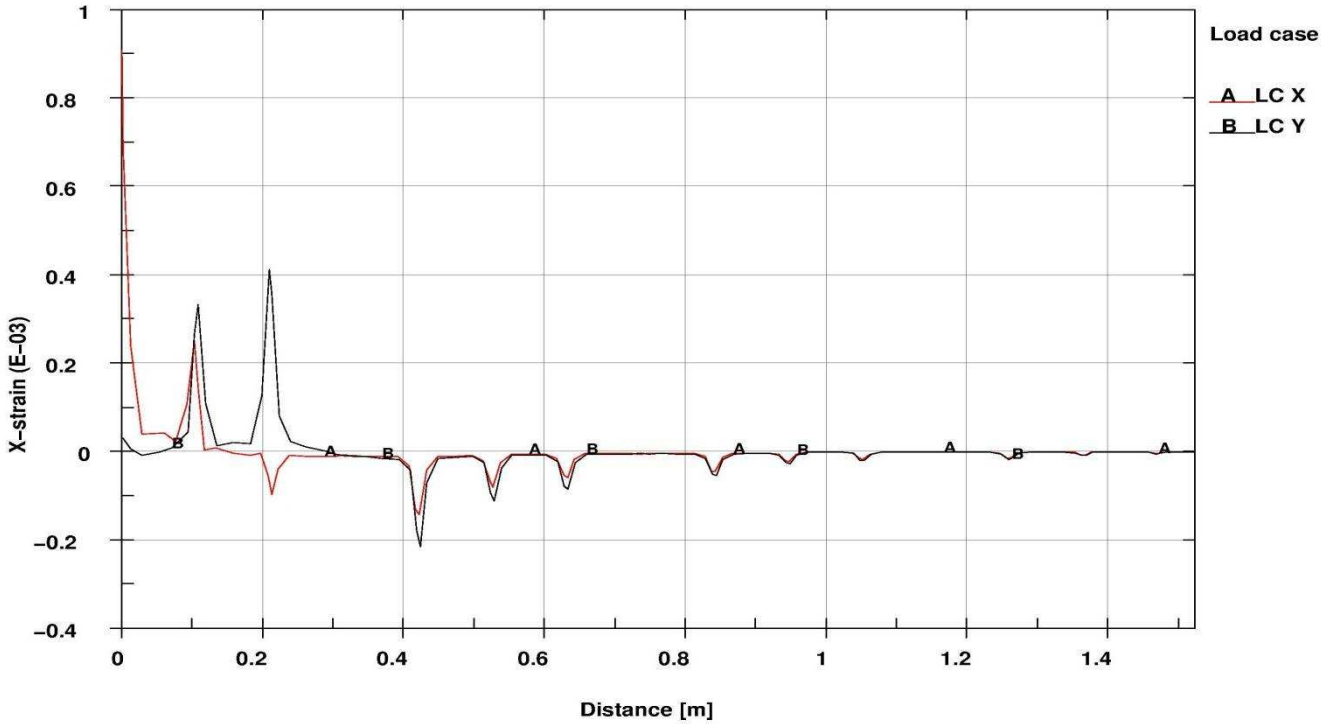


# Blocks, Joints and Bedding Sand

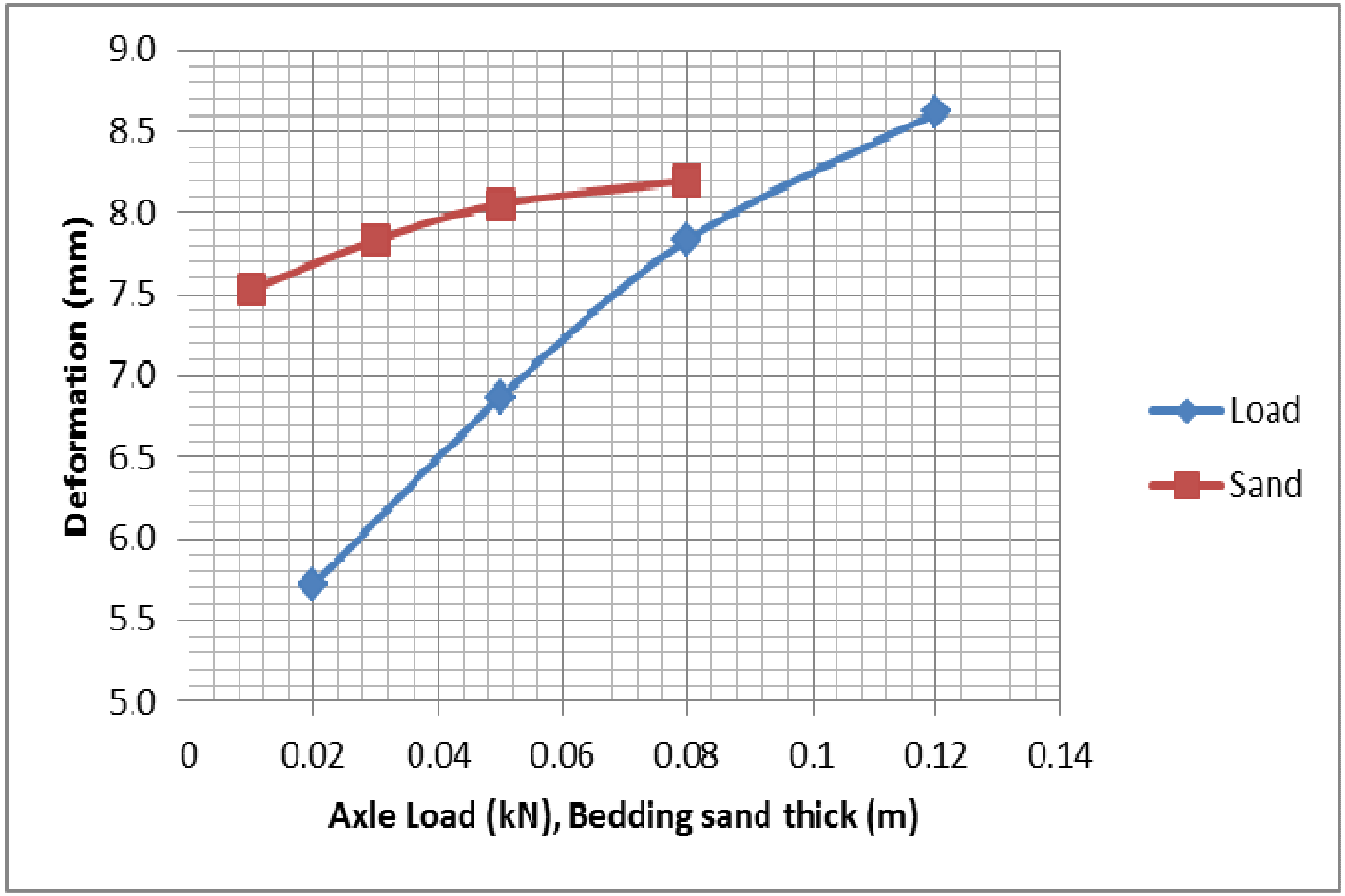
Finite element analysis shows:

- Tensile strain at the bottom of the joint between blocks and at the top of the bedding sand
- Bedding sand tend to move away from joint between blocks
- Blocks tend to move apart and joints between blocks tend to open
- Water entering aggravates the situation
- Result: Deformation of the pavement, voids below blocks resulting in loose blocks that may also crack

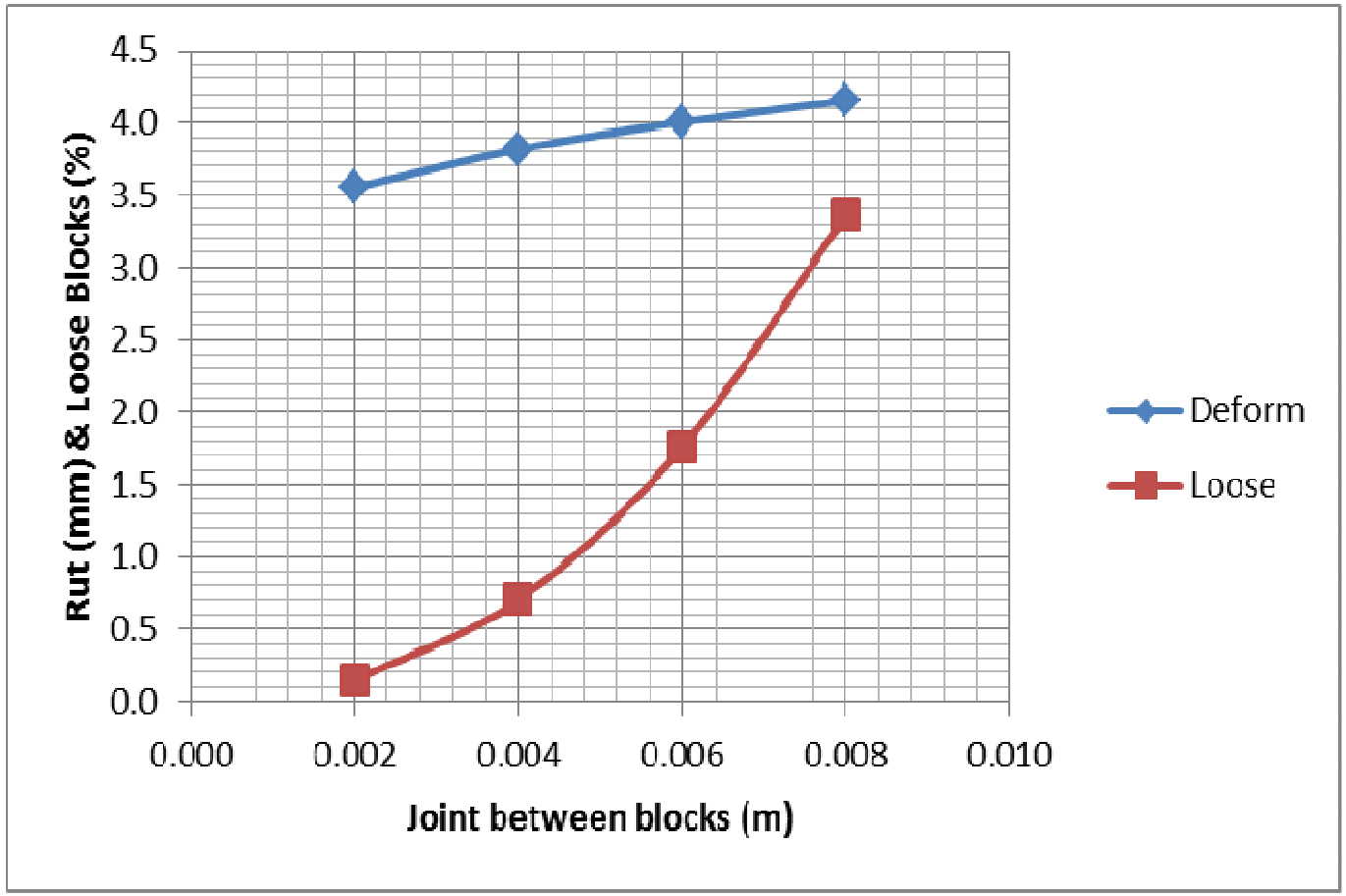
# Strain below the blocks at the surface of the bedding sand



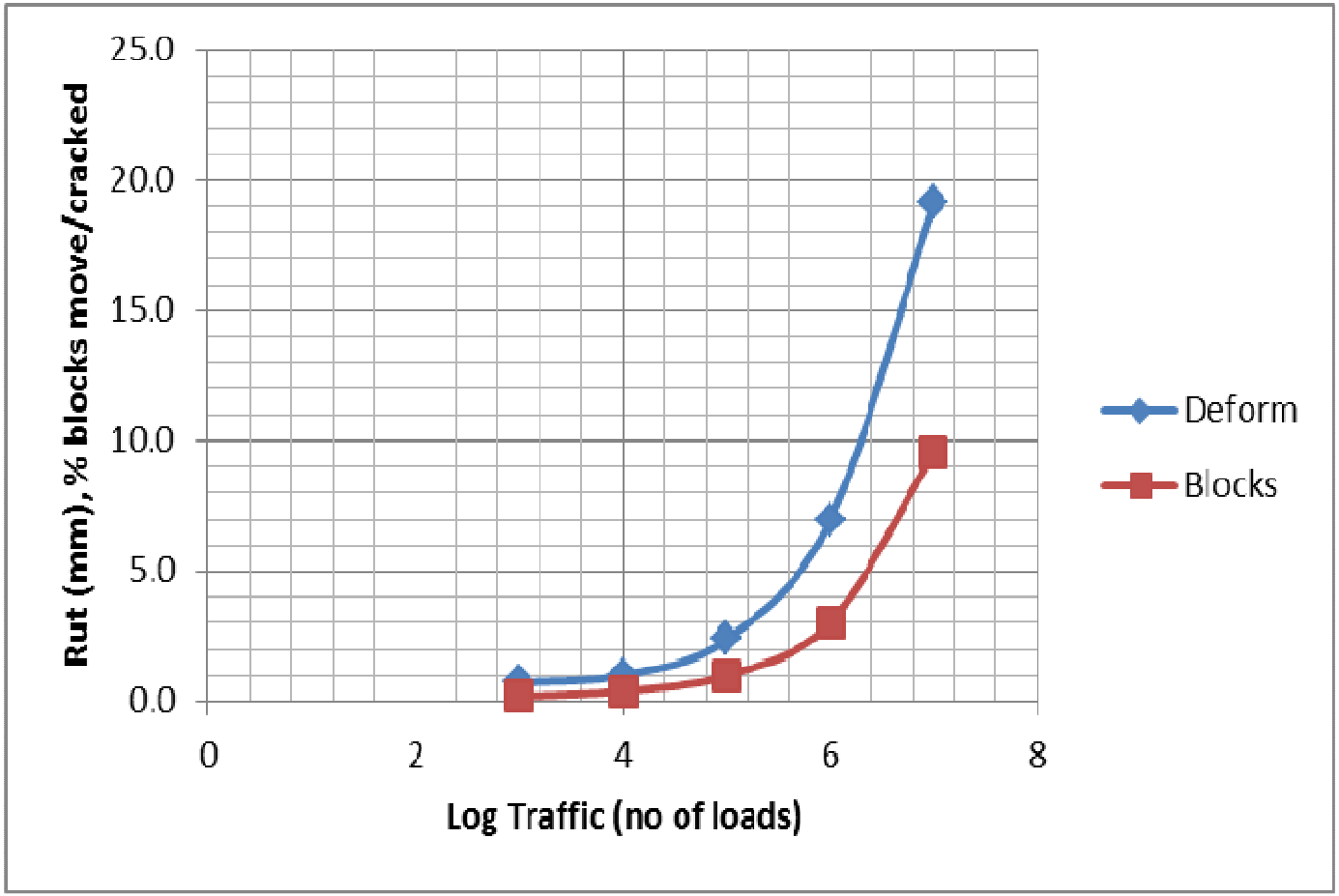
# Effect of axle loads & bedding sand thickness on deformation



# Effect of joint width on deformation & loose/cracked blocks



# Deformation and cracked/moving blocks with increased number of loads



# Way Forward

- Adjust the load transfer model in cncPAVE
- Refine the models for predicting IRI
- Develop test method to quantify erosion
- Develop the computer program to design block pavements
- Refine all models using field data and practical experience and integrate it into cncPAVE
- Incorporate cncPAVE into the SAPDM.

Assistance from industry to calibrate the block pavement design method by providing data on performance will be greatly appreciated.

Thank you

(pieterst@lantic.net)