TPF-5(282)

Demonstration of Network Level Pavement Structural Evaluation with Traffic Speed Deflectometer

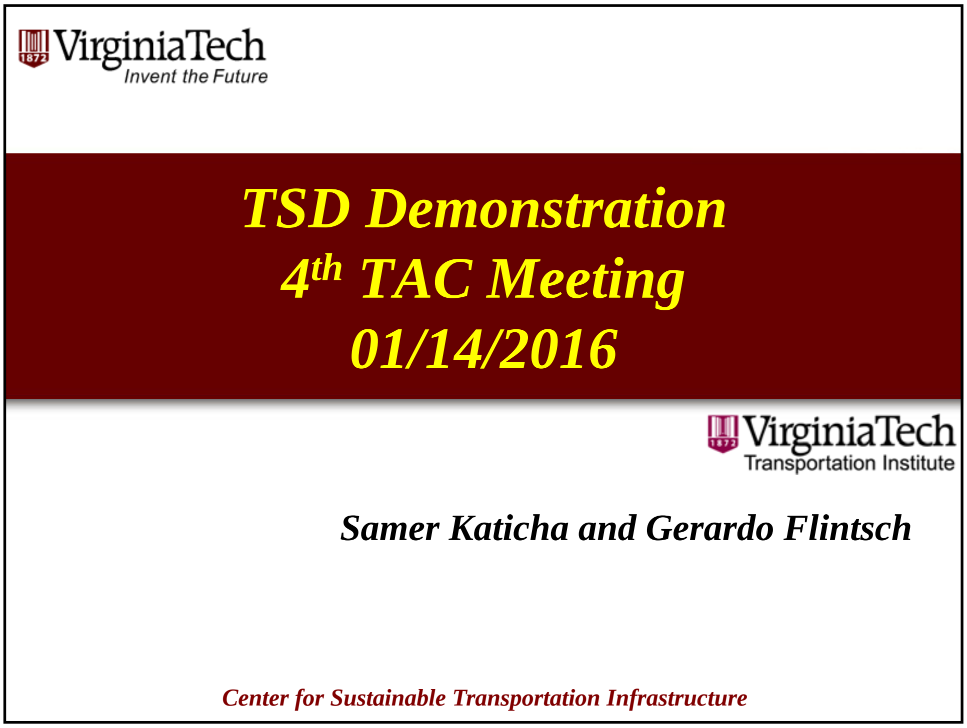
Fourth Meeting of the Technical Advisory Committee

January 14, 2016
Conference Room 302
The Walter E. Washington Convention Center
801 Mt Vernon Pl NW, Washington, DC 20001

Flexible Agenda

9:00 - 9:15	Opening remarks and introductions (Siva/All)
9:15- 10:00	Update on second round of testing and analysis (Samer Katicha/Gerardo Flintsch)
10:00 – 12:00	Data analysis and final report ✓ TSD data ✓ Potential structural indices and their strengths and value in SHA PMS process ✓ Auxiliary data ✓ Analysis ✓ Example Implementation of TSD data into PMS
12:00 - 1:00	Lunch
1:00 - 1:45	The Australian experience (Kim Sedgwick/Richard Wix - ARRB)
1:45 - 2:15	TSD device and data analysis update (Jørgen Krarup/Greenwood Engineering)
2:15 - 2:45	Update on DaRTS and BeCATS activities (Brian Ferne) ✓ DaRTS4 meeting ✓ HiSPEQ ✓ Other
2:45 - 3:30	Implementation of measurements into pavement management system - discussion (All)
3:30 - 4:00	Feedback from consortium members and next steps

Web/Teleconference for those wishing to attend remotely:
Webinar URL: https://connectdot.connectsolutions.com/siva
Call-in numbers: 1-888-557-8511 (toll free) or 1-215-446-3649 (toll paid)
Access Code: 4993555
(audio will also be available through the computer speaker/microphone)



TSD Demonstration
4th TAC Meeting
01/14/2016

Samer Katicha and Gerardo Flintsch

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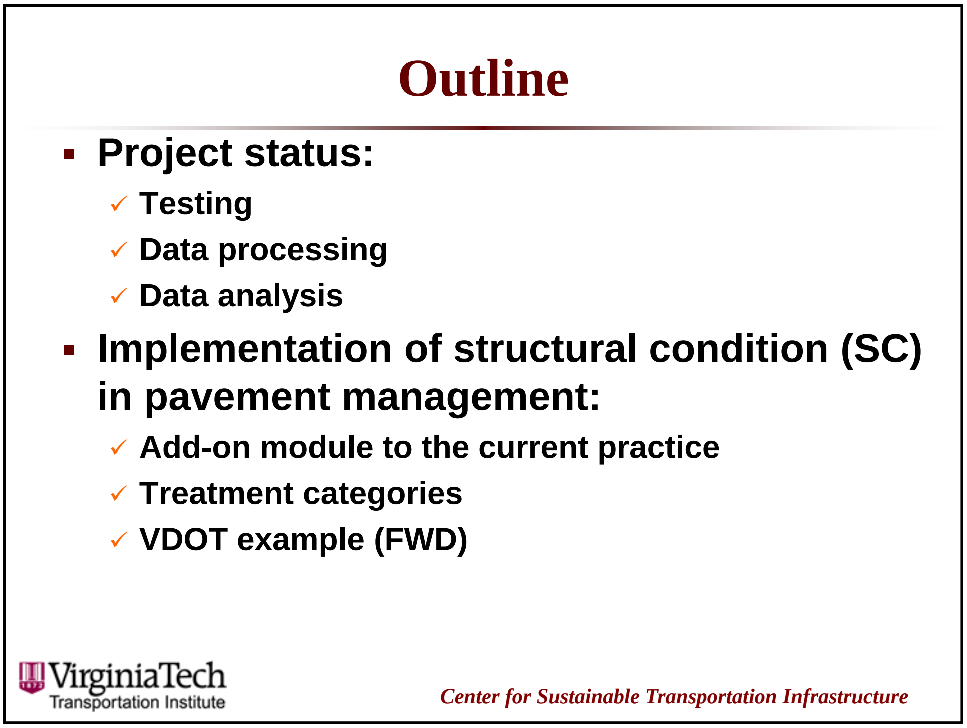

Outline

- **Project status:**
  - ✓ **Testing**
  - ✓ **Data processing**
  - ✓ **Data analysis**
- **Implementation of structural condition (SC) in pavement management:**
  - ✓ **Add-on module to the current practice**
  - ✓ **Treatment categories**
  - ✓ **VDOT example (FWD)**

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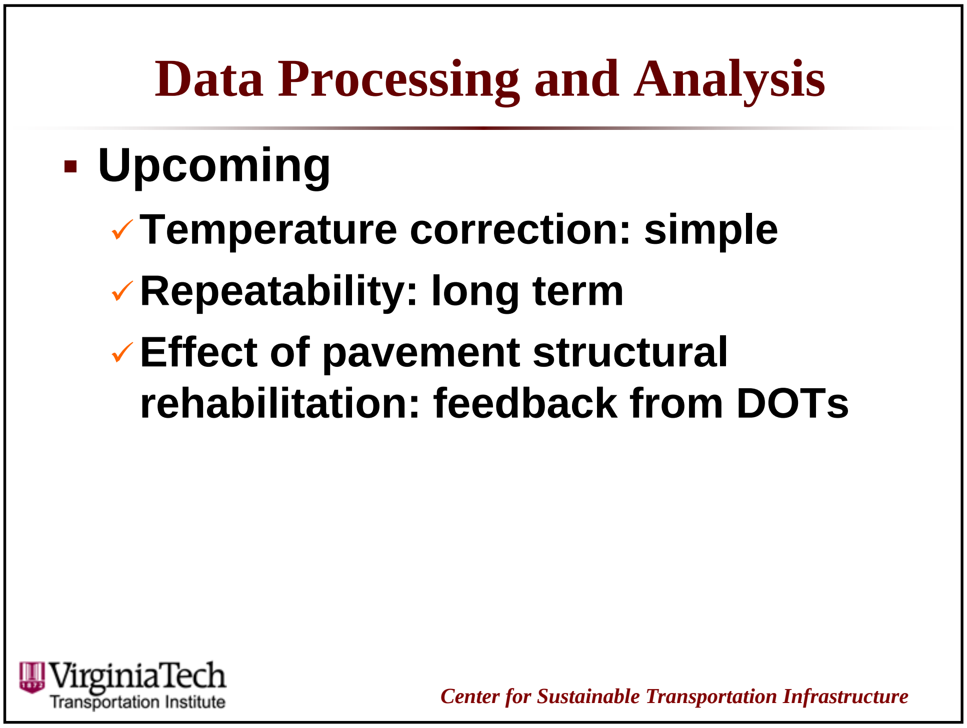
Project Status

- **Testing completed**
  - ✓ **Total: 4,500 miles (excluding Idaho)**
  - ✓ **Range: 300 to 1,000 miles**
- **Data processing**
  - ✓ **Most data processed**
  - ✓ **Some data need to be reprocessed**
- **Data analysis**
  - ✓ **Second round of testing still not analyzed**

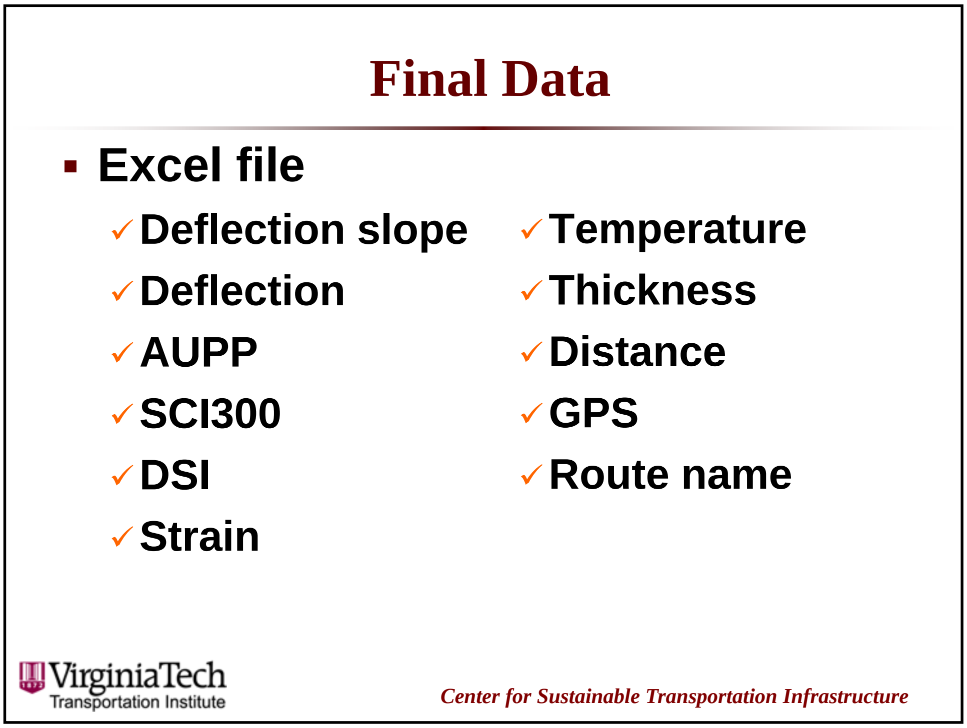
Data Analysis

- **Already performed**
  - ✓ **Repeatability**
  - ✓ **Comparison with FWD**
  - ✓ **Calculation of indices: SNeff, SCI, AUPP**
  - ✓ **Comparison with PMS structural condition: SNeff in Pennsylvania**
  - ✓ **Backcalculation**
  - ✓ **Validation of TSD measurements with pavement condition**



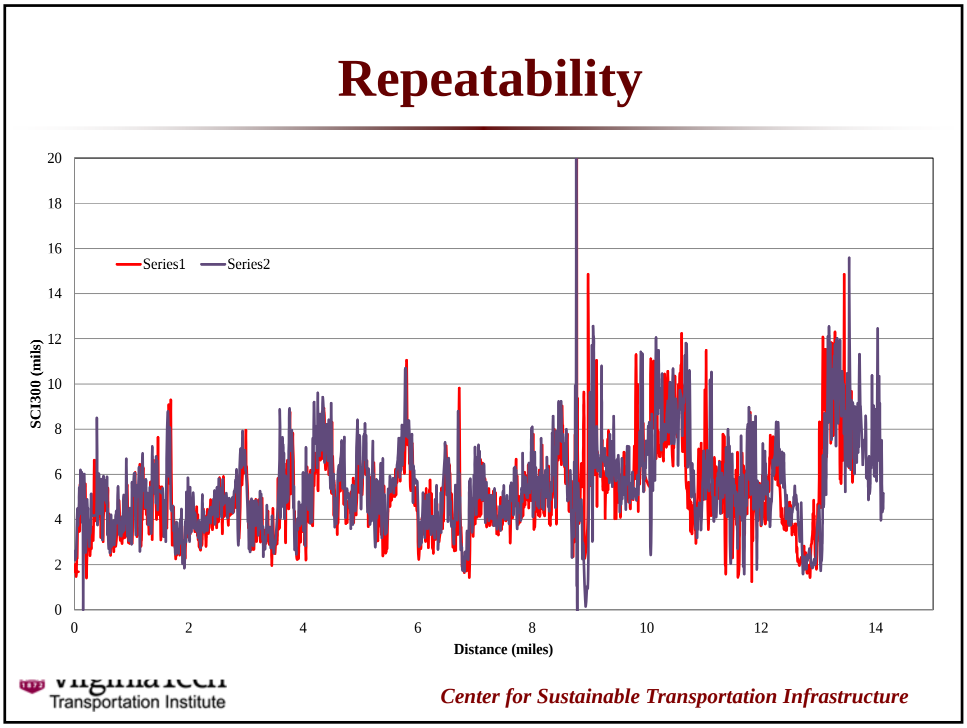
Data Processing and Analysis

- Upcoming
  - ✓ Temperature correction: simple
  - ✓ Repeatability: long term
  - ✓ Effect of pavement structural rehabilitation: feedback from DOTs



Final Data

- Excel file
  - ✓ Deflection slope
  - ✓ Deflection
  - ✓ AUPP
  - ✓ SCI300
  - ✓ DSI
  - ✓ Strain
  - ✓ Temperature
  - ✓ Thickness
  - ✓ Distance
  - ✓ GPS
  - ✓ Route name



Repeatability

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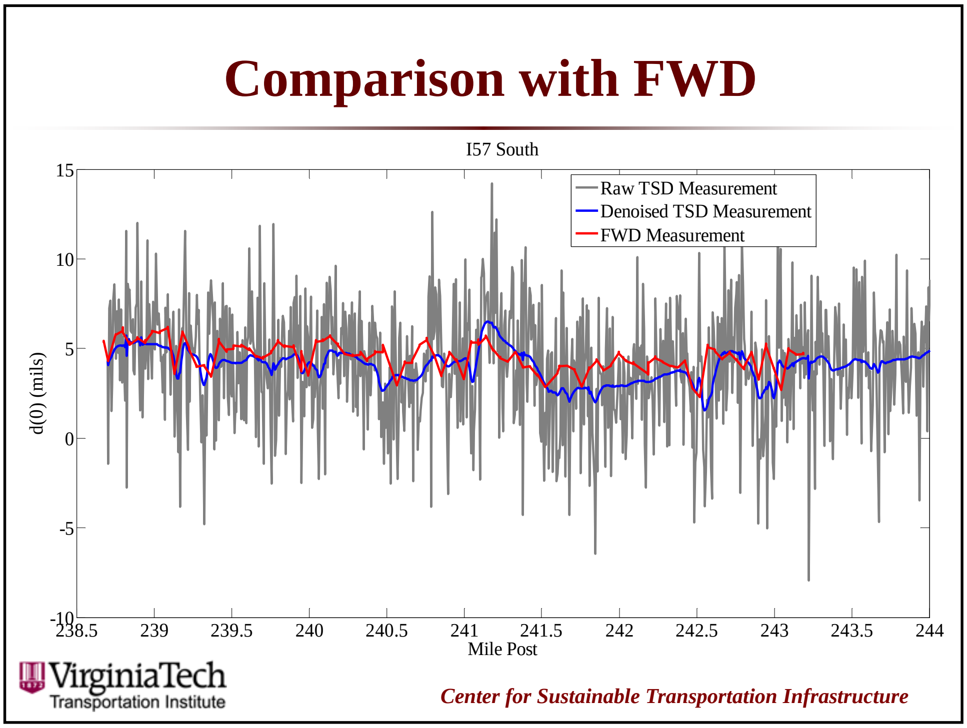

Comparison with FWD

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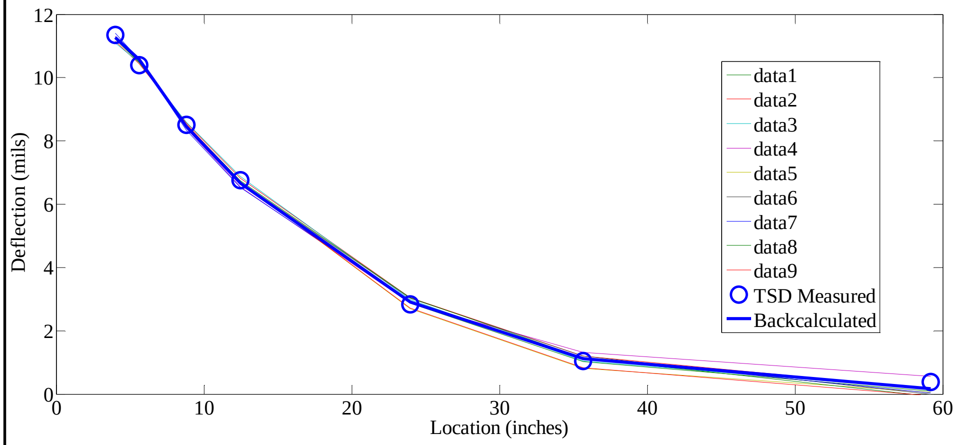
Backcalculation



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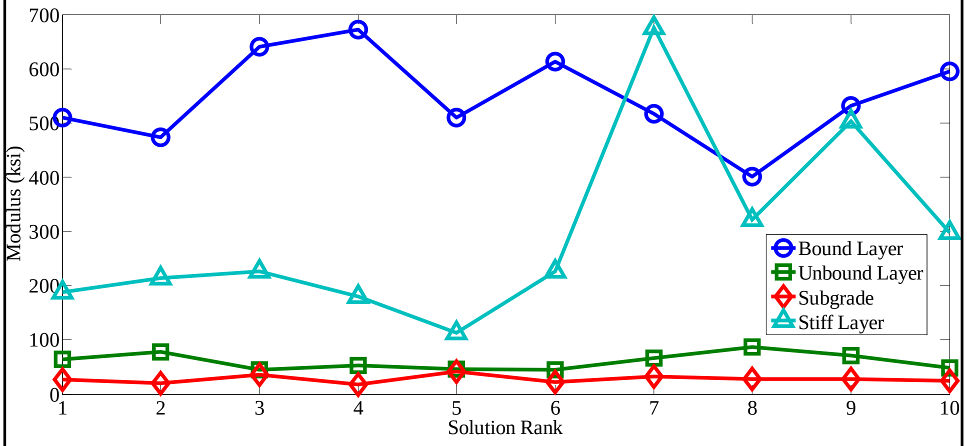
Backcalculation



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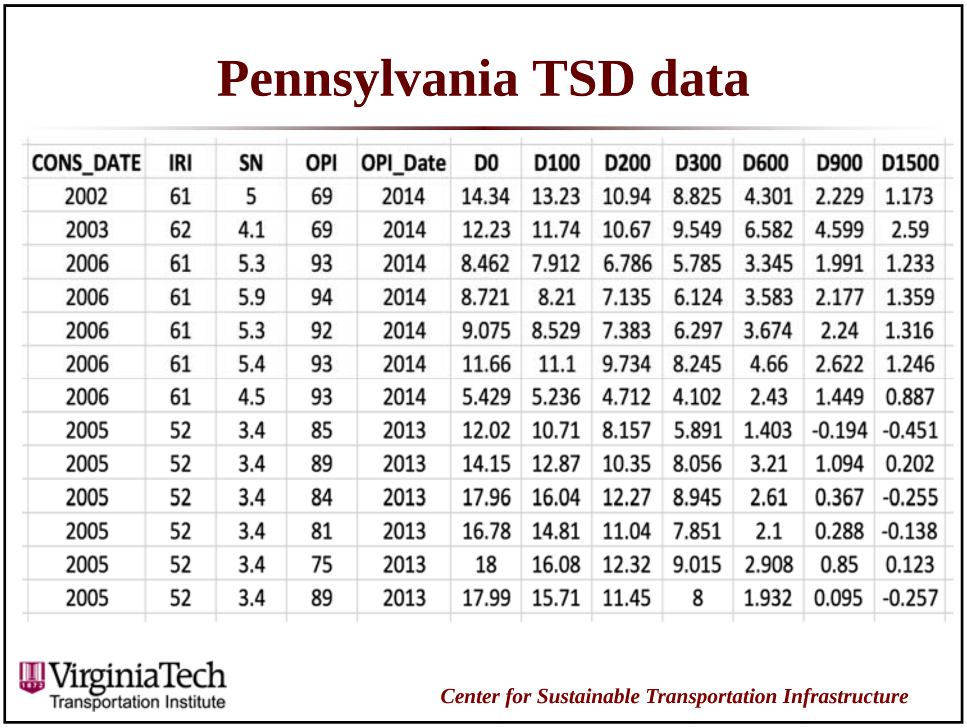
Validation with Pavement Condition

- Pavement condition data (Pennsylvania)
  - ✓ OPI (overall pavement index)
  - ✓ Construction date
  - ✓ OPI date
- Regression:
  - ✓ OPI vs Age and Structural Condition

Overall Pavement Index (OPI)

- OPI is a 0–100 index that combines IRI-based Roughness Index and individual pavement distress indices.
- $OPI = (0.25 \times RUF) + (0.15 \times FCI) + (0.125 \times TCI) + (0.10 \times MCI) + (0.10 \times EDI) + (0.05 \times BPI) + (0.05 \times RWI) + (0.175 \times RUT)$
- RUF = 100 - ((0.27 x IRI) - 11)
- FCI–Fatigue Cracking Index; TCI–Transverse Cracking Index; MCI–Miscellaneous Cracking Index; EDI–Edge Deterioration Index; BPI–Bituminous Patching Index; RWI–Raveling / Weathering Index; RUT–Rut Depth Index



Pennsylvania TSD data

CONS_DATE	IRI	SN	OPI	OPI_Date	D0	D100	D200	D300	D600	D900	D1500
2002	61	5	69	2014	14.34	13.23	10.94	8.825	4.301	2.229	1.173
2003	62	4.1	69	2014	12.23	11.74	10.67	9.549	6.582	4.599	2.59
2006	61	5.3	93	2014	8.462	7.912	6.786	5.785	3.345	1.991	1.233
2006	61	5.9	94	2014	8.721	8.21	7.135	6.124	3.583	2.177	1.359
2006	61	5.3	92	2014	9.075	8.529	7.383	6.297	3.674	2.24	1.316
2006	61	5.4	93	2014	11.66	11.1	9.734	8.245	4.66	2.622	1.246
2006	61	4.5	93	2014	5.429	5.236	4.712	4.102	2.43	1.449	0.887
2005	52	3.4	85	2013	12.02	10.71	8.157	5.891	1.403	-0.194	-0.451
2005	52	3.4	89	2013	14.15	12.87	10.35	8.056	3.21	1.094	0.202
2005	52	3.4	84	2013	17.96	16.04	12.27	8.945	2.61	0.367	-0.255
2005	52	3.4	81	2013	16.78	14.81	11.04	7.851	2.1	0.288	-0.138
2005	52	3.4	75	2013	18	16.08	12.32	9.015	2.908	0.85	0.123
2005	52	3.4	89	2013	17.99	15.71	11.45	8	1.932	0.095	-0.257

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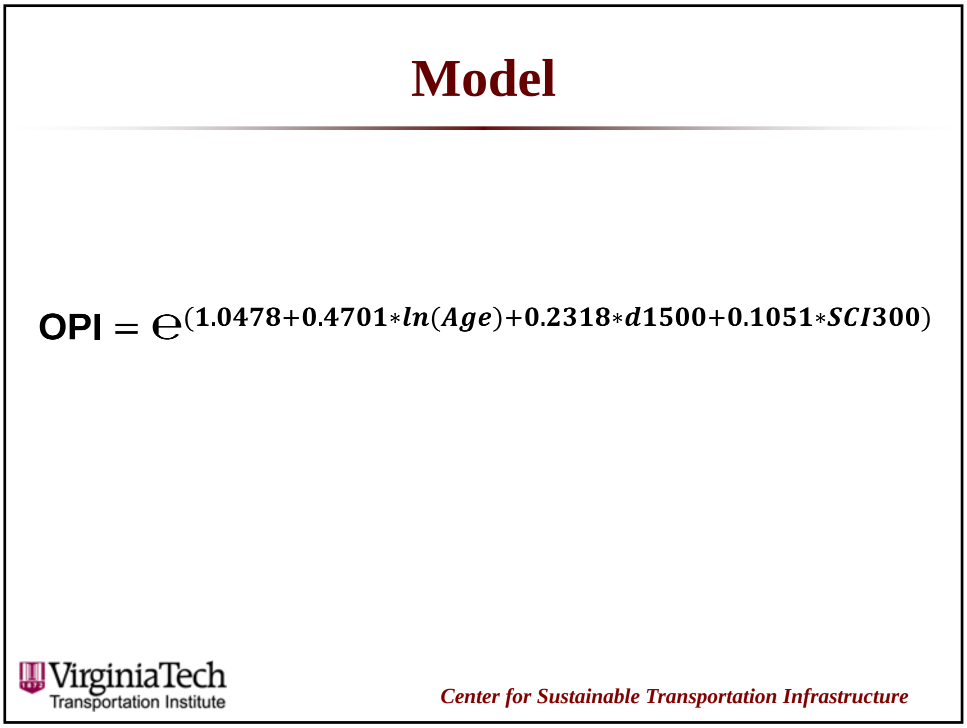

Model

$$\text{OPI} = e^{(1.0478+0.4701*ln(Age)+0.2318*d1500+0.1051*SCI300)}$$

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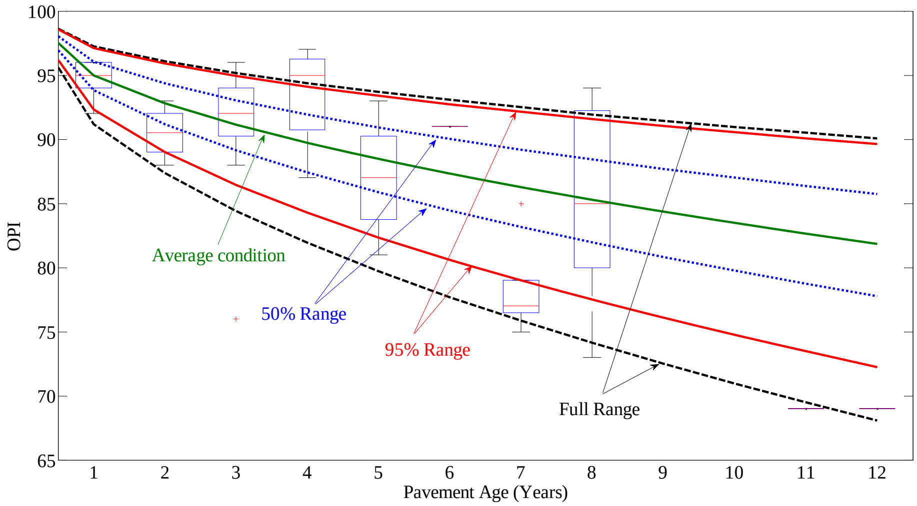
Result



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Final Report

- One report for each state DOT:
  - ✓ Specific to DOT data
- One report summarizing all research results shared between all DOTs

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Implementation into PMS

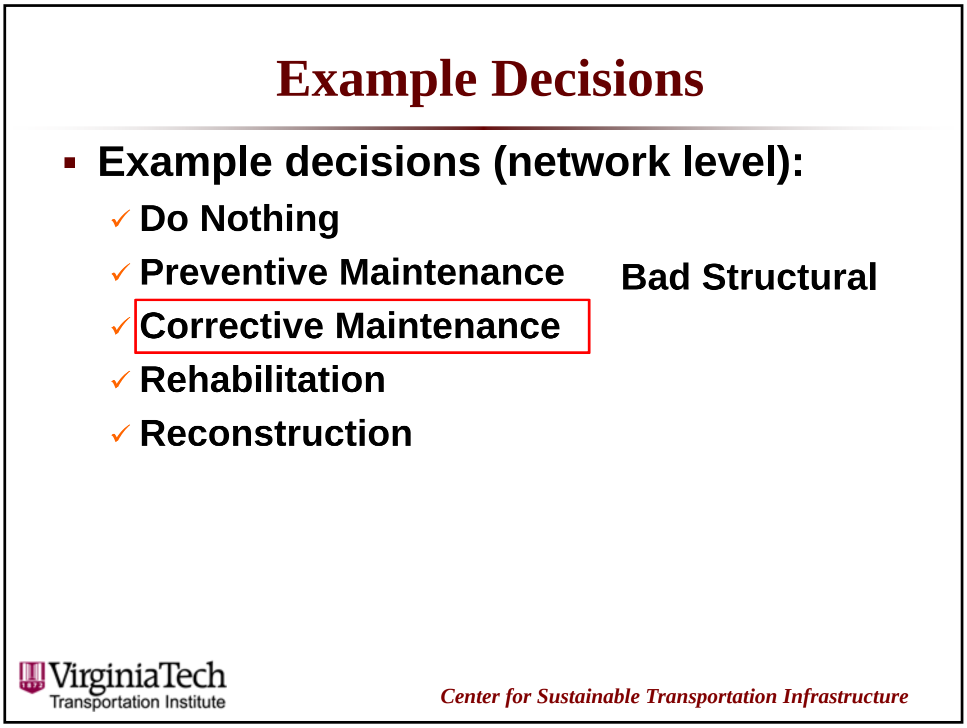
- Implement TSD results in pavement management system
- Complement current practice:
  - ✓ Current PMS decision
  - ✓ Structural Condition

} Improved Decision

Example Decisions

- Example decisions (network level):
  - ✓ Do Nothing
  - ✓ Preventive Maintenance
  - ✓ Corrective Maintenance
  - ✓ Rehabilitation
  - ✓ Reconstruction

Good Structural



Example Decisions

- Example decisions (network level):
  - ✓ Do Nothing
  - ✓ Preventive Maintenance
  - ✓ Corrective Maintenance
  - ✓ Rehabilitation
  - ✓ Reconstruction

Bad Structural

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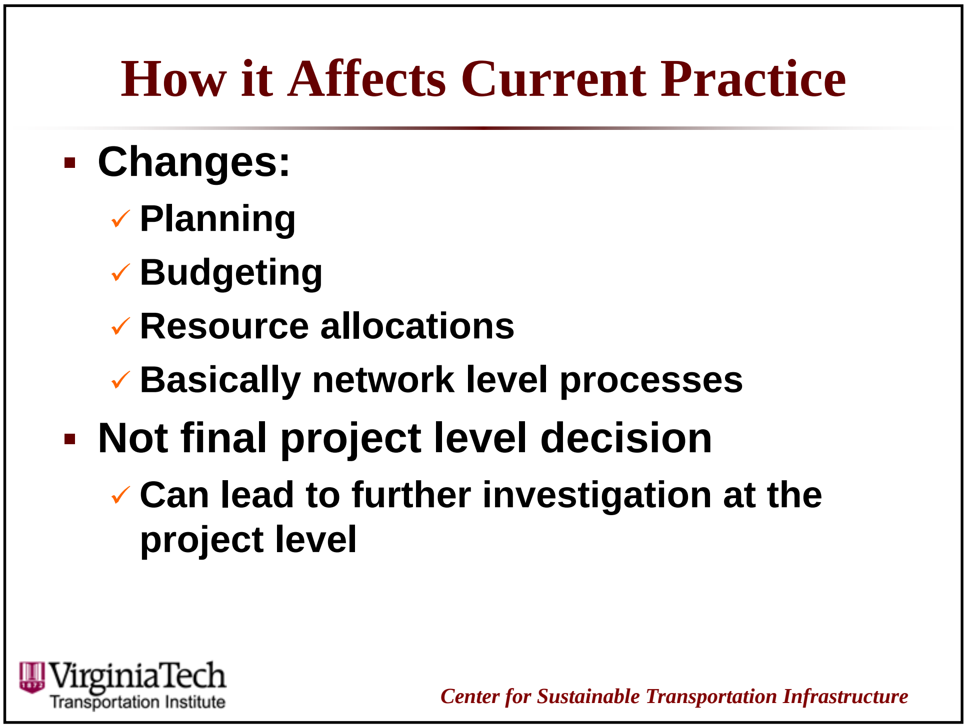

How it Affects Current Practice

- Changes:
  - ✓ Planning
  - ✓ Budgeting
  - ✓ Resource allocations
  - ✓ Basically network level processes
- Not final project level decision
  - ✓ Can lead to further investigation at the project level

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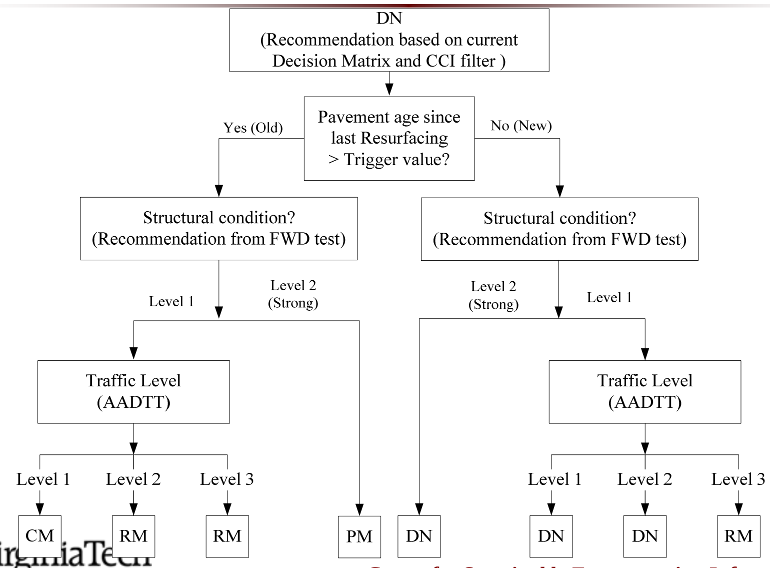
Example VDOT

- **Current practice:**
  - ✓ **Decision Matrices: distress from survey triggers action**
  - ✓ **CCI filter: triggered action changed based on CCI (0 to 100)**
- **Enhanced decision process**
  - ✓ **Age**
  - ✓ **Structural condition**
  - ✓ **Traffic level**

Example (Do Nothing)



DN (Recommendation based on current Decision Matrix and CCI filter)

Pavement age since last Resurfacing > Trigger value?

Yes (Old)

No (New)

Structural condition? (Recommendation from FWD test)

Structural condition? (Recommendation from FWD test)

Level 1

Level 2 (Strong)

Level 2 (Strong)

Level 1

Traffic Level (AADTT)

Traffic Level (AADTT)

Level 1

Level 2

Level 3

Level 1

Level 2

Level 3

CM

RM

RM

PM

DN

DN

DN

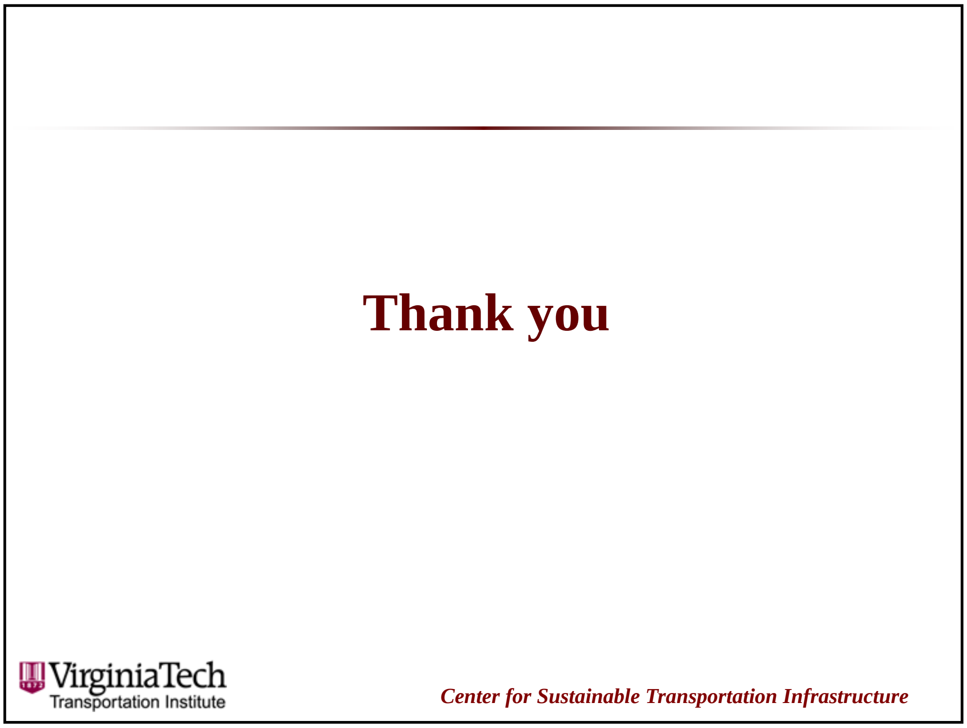
RM

Other Parameters

- Road categories:
  - ✓ Already included in decision process
    - ❑ Option 1: do not worry about it anymore
    - ❑ Option 2: include it with structural condition
- Auxiliary variables:
  - ✓ Pavement thickness: incorporated in the calculation of the structural index
  - ✓ Traffic: included

Procedure for Structural Condition

- Condition index:
  - ✓ DSI (deflection slope index)
  - ✓ SCI (surface curvature index)
- Tensile strain bottom of asphalt layer:
  - ✓ Regression vs condition index (DSI or SCI)
- Temperature correction
- Determine structural adequacy



Thank you

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The Australian TSD Experience

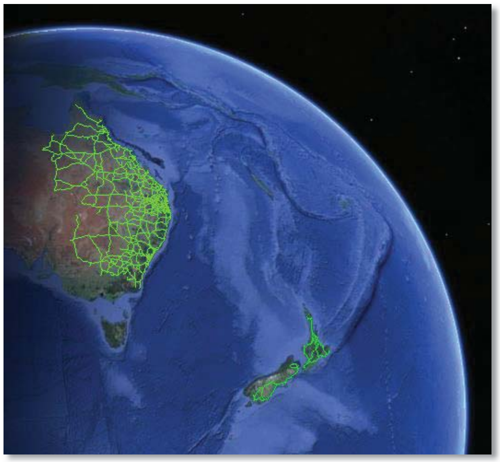
Fourth Meeting of the TPF-5(282) Technical Advisory Committee
14 January 2016, Washington, DC

Trusted advisor to road agencies

Our purpose

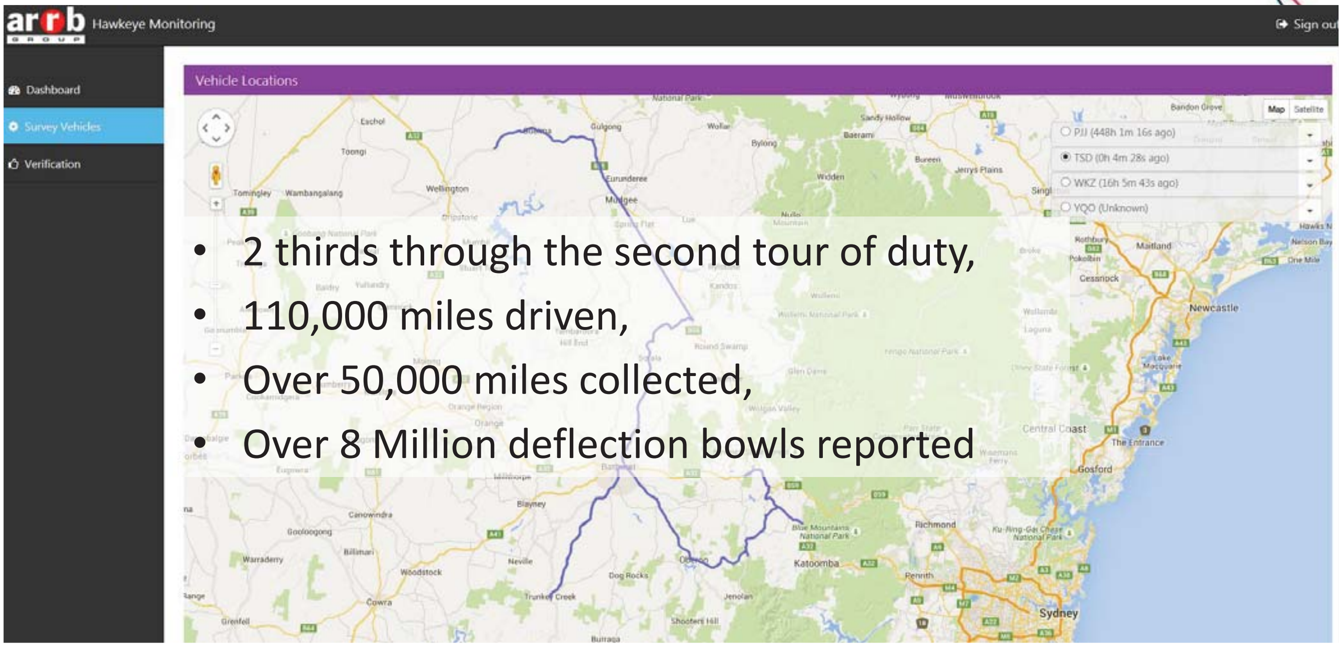
Trusted advisor on roads and transport

Where we've come from



Australian/NZ TSD Collection Route

Current TSD Project Progress



○ PJJ (448h 1m 16s ago)
● TSD (0h 4m 28s ago)
○ WKZ (16h 5m 43s ago)
○ YQO (Unknown)

- 2 thirds through the second tour of duty,
- 110,000 miles driven,
- Over 50,000 miles collected,
- Over 8 Million deflection bowls reported

ARRB TSD's

- 7 Doppler Lasers
- Automatic Crack Detection (through LCMS)
- 5 laser profiler
- Video Imaging System
- Gipsitrac (enabling geometry)
- GPS/DGPS

The ARRB TSD

SAFE FAST EFFICIENT

Safe

- TSD moves with traffic flow with no external traffic control requirements
- TSD can complete an 12,000 mile network in 12 weeks
- The equivalent FWD network testing will take 15 years
- Reduces risk exposure and severity considerably over other stationary slow moving devices

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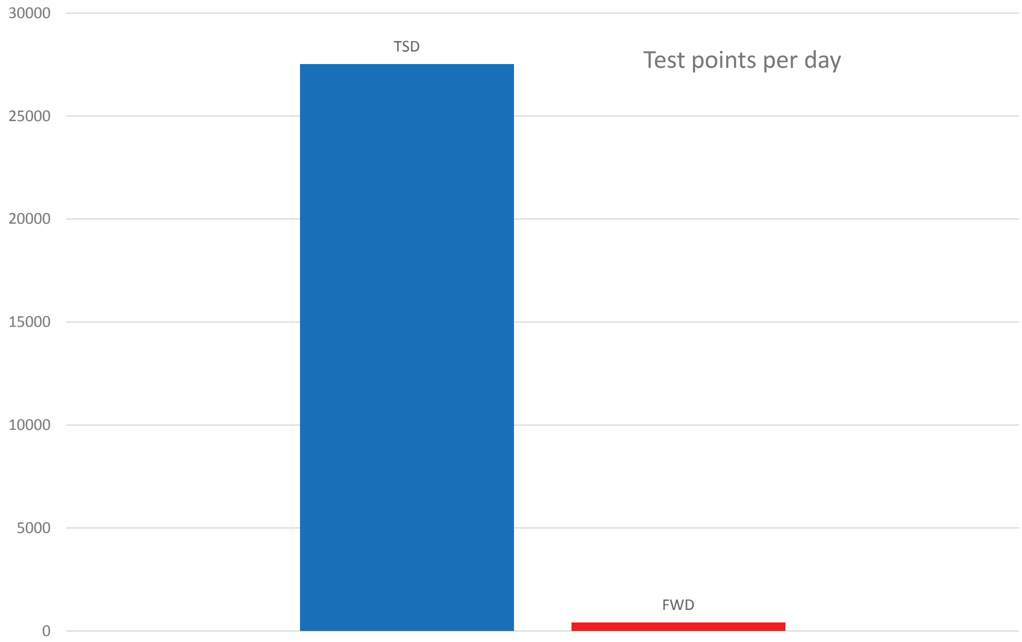
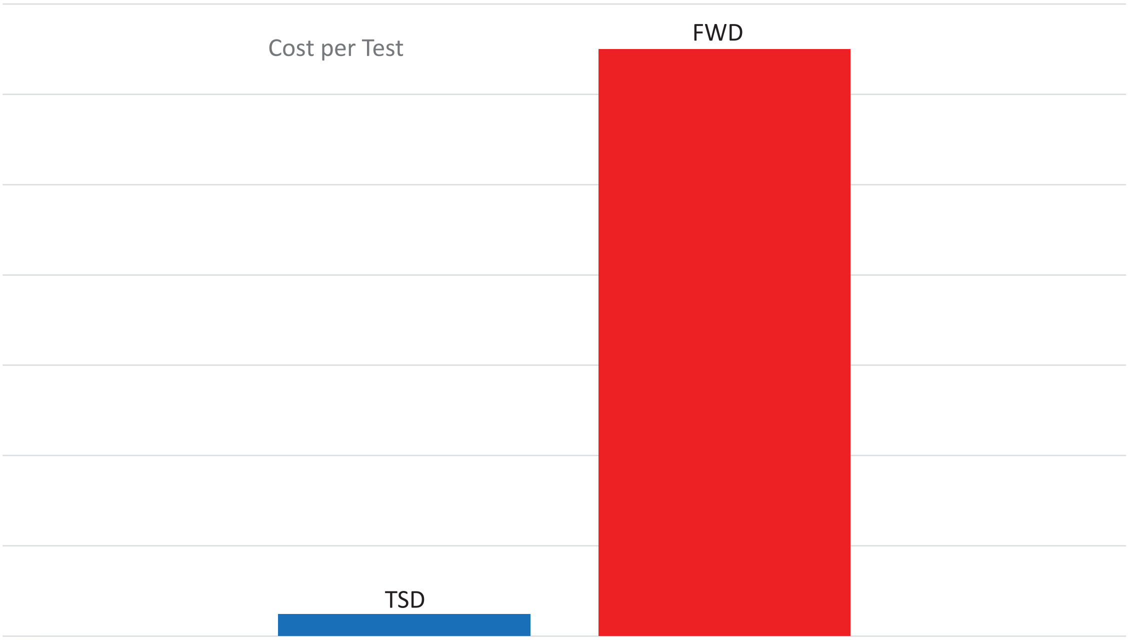
Fast



Efficient



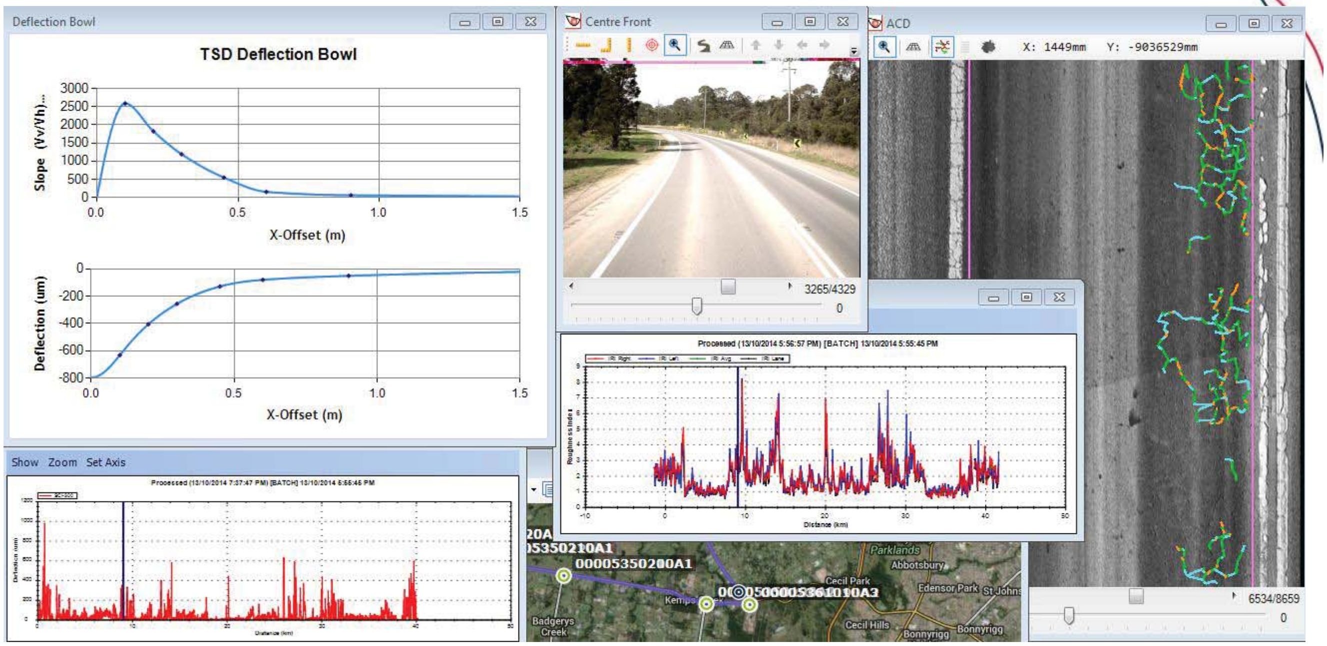
Data Outputs

Trusted advisor to road agencies

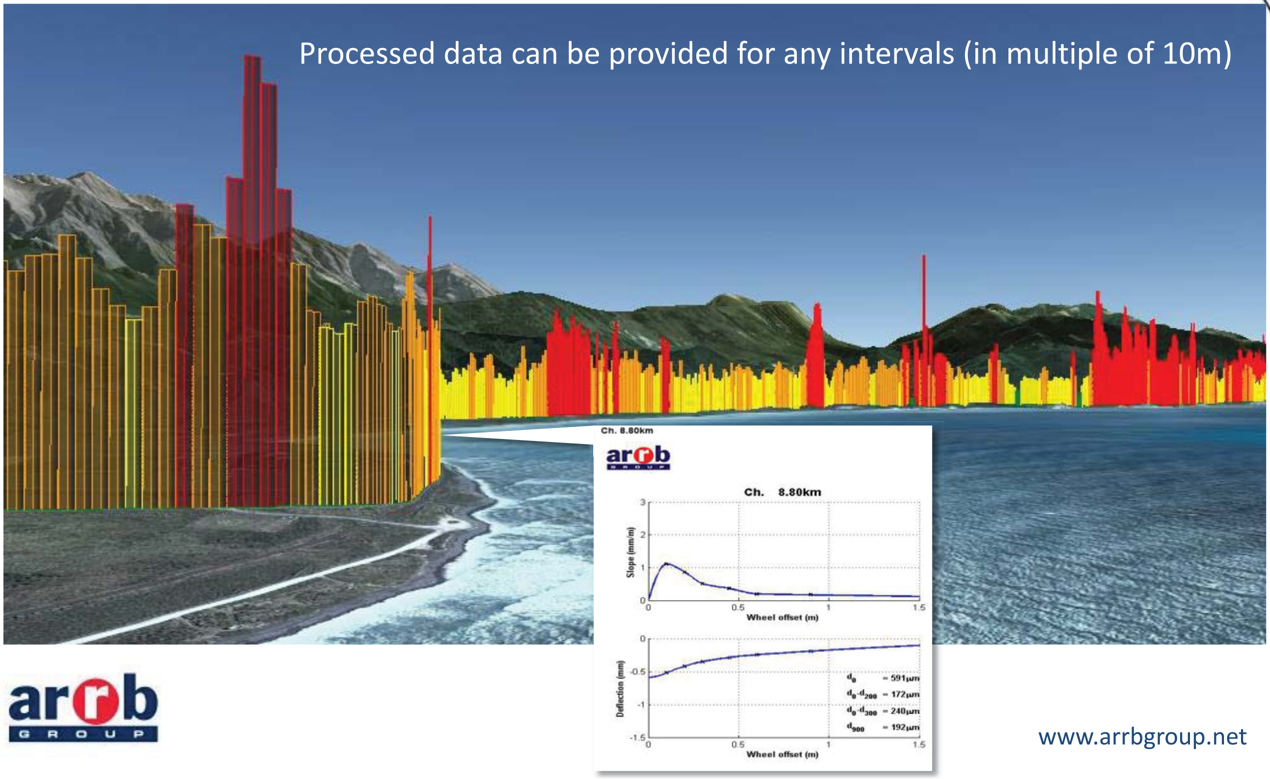
Integration - ARRB development

- LCMS fully integrated and mounted on Hawkeye survey platform
  - Reference points
  - Events
  - DGPS
  - Distance
  - Supplementary imagery
  - Integrated viewing software
  - All other Hawkeye features
- Evaluating current and future applications
- Custom Reports - Access to raw crack data enables us to customise result reporting according to client requirements.

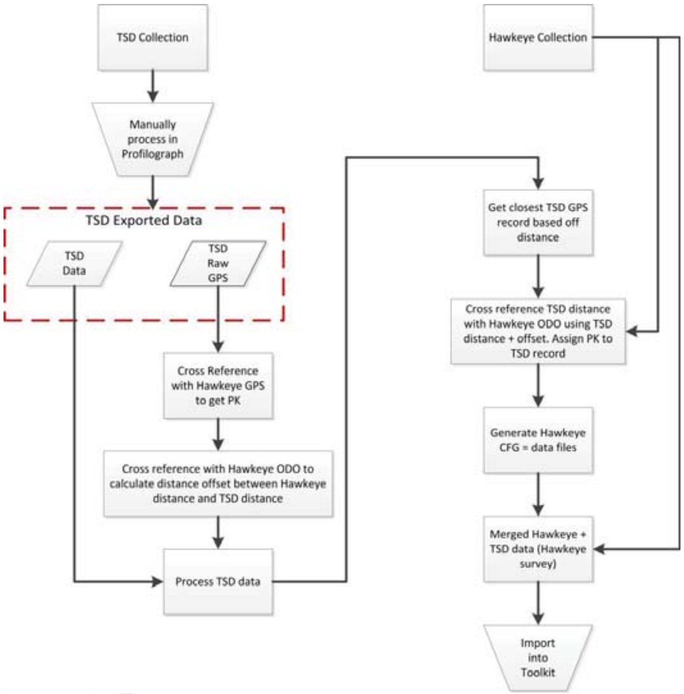
Simultaneous Collection



Data outputs


Processed data can be provided for any intervals (in multiple of 10m)

Data Alignment


TSD Collection

Manually process in Profilograph

TSD Exported Data

TSD Data

TSD Raw GPS

Cross Reference with Hawkeye GPS to get PK

Cross reference with Hawkeye ODO to calculate distance offset between Hawkeye distance and TSD distance

Process TSD data

Hawkeye Collection

Get closest TSD GPS record based off distance

Cross reference TSD distance with Hawkeye ODO using TSD distance + offset. Assign PK to TSD record

Generate Hawkeye CFG = data files

Merged Hawkeye + TSD data (Hawkeye survey)

Import into Toolkit

Common reference device

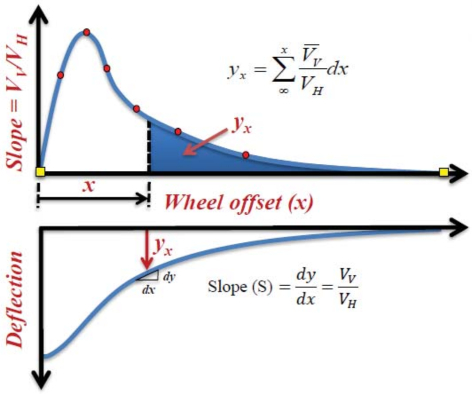
- Odometer (distance)
- GPS receiver (coordinates)

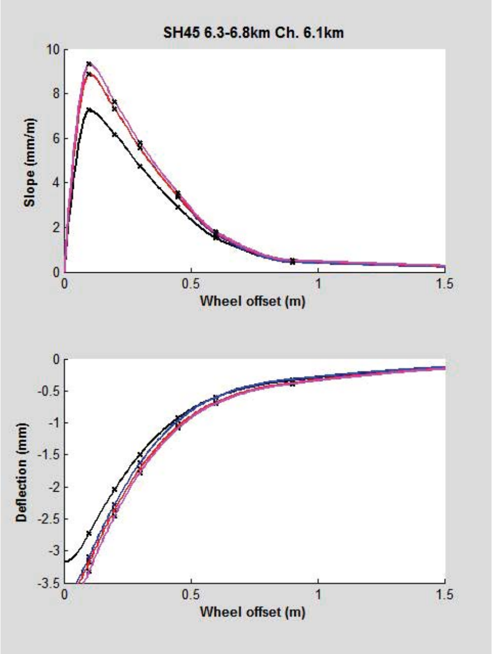
Merge utility

- Primary key GPS time
- Cross reference TSD distance

Data outputs AUTC

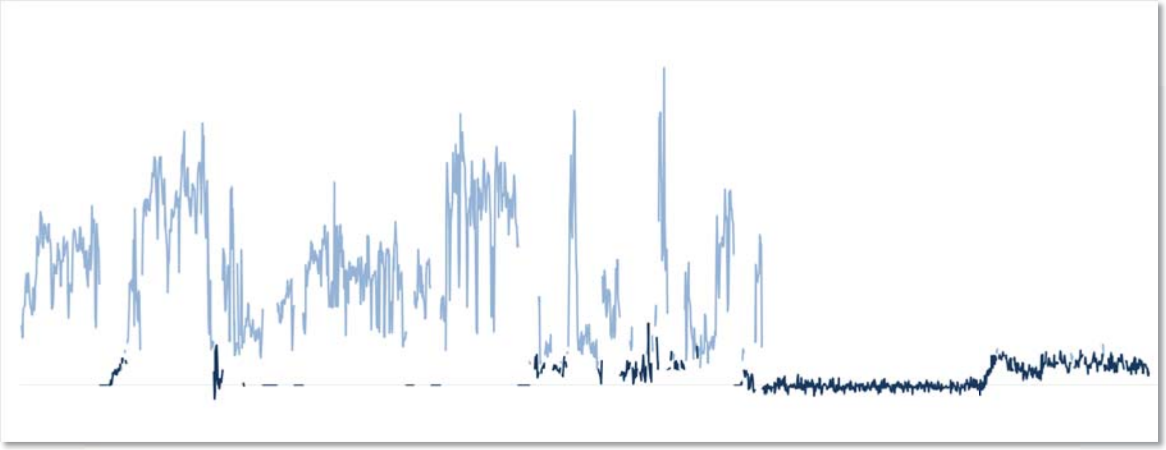
Area under the curve (AUTC) calculations
- TSD data calculated into a deflection bowl
- Deflections at any offset location
- Very good correlation to FWD data



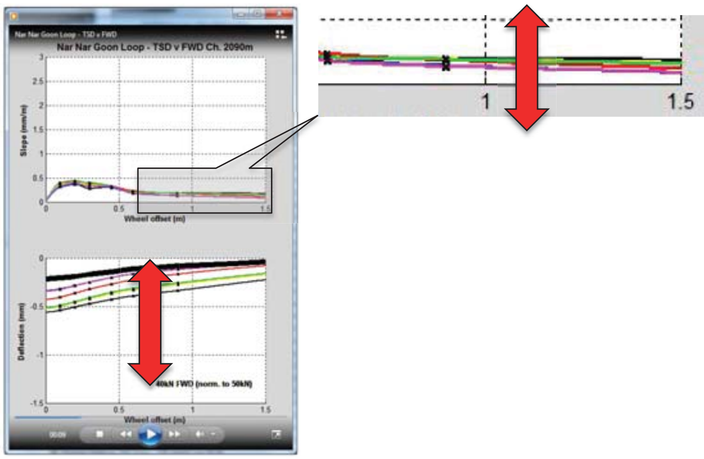


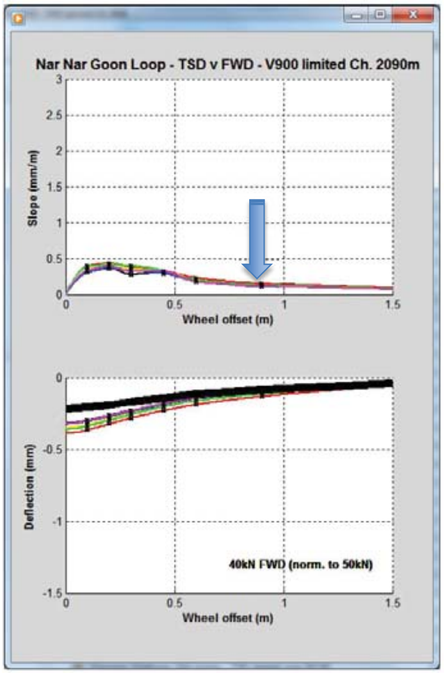
Improvements – Software refinement

- Refining analysis models
- Increasing valid AUTC calculations on ‘raw’ velocity
  - minimum of three valid velocity readings
  - = more data reported



Software “Tail Taming”

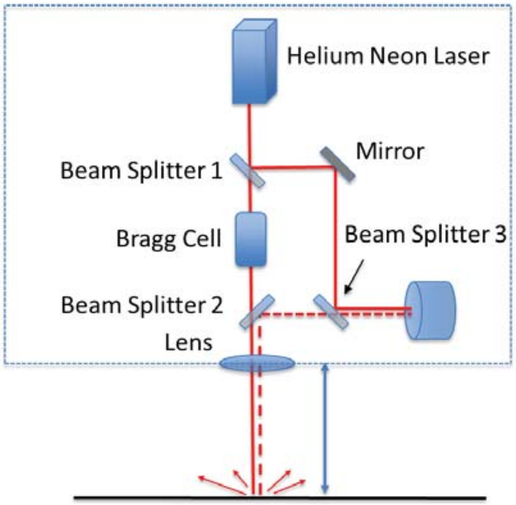




- Increases the repeatability
- Tightens the AUTC model calculation
- = better quality data reported

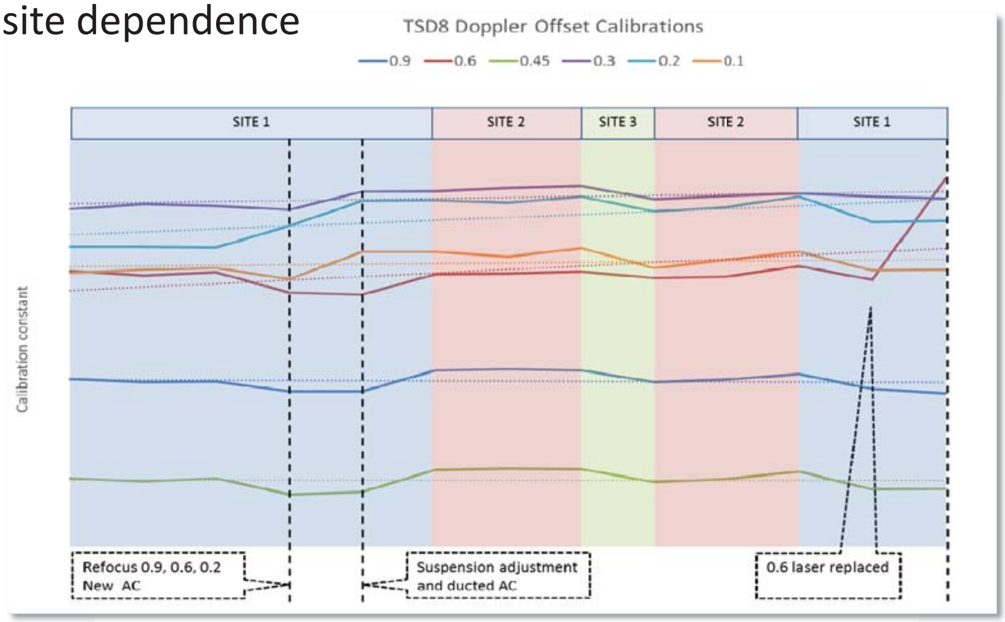
Improvements - Hardware

- Re-engineering and strengthening components
- High capacity temperature control
- Tuning hydraulics and power supply systems
- Laser focusing device
  - higher data rate
  - = more valid data



Doppler Calibrations

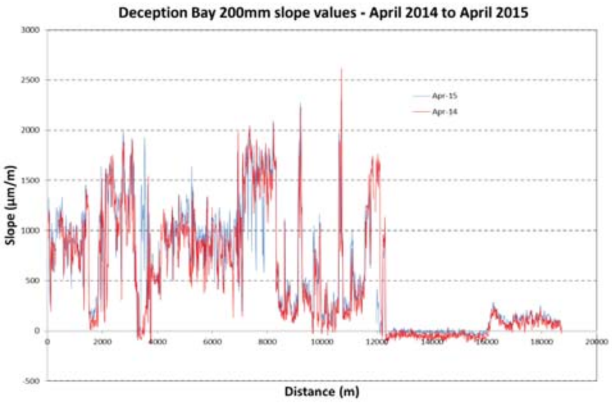
- Maintaining consistency
- Reducing site dependence



Validations and benchmarking

Numerous validations and historical loops:

- Good system stability
- Good internal repeatability
- Good historical repeatability
- Good deflection comparability



TSD AUTC Method
(Heavy Mathematics Section)

Trusted advisor to road agencies

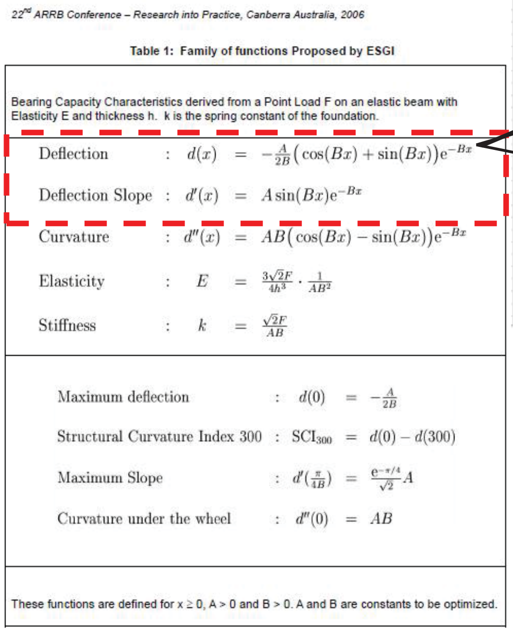
Doppler deflection velocity – what's that?

- Doppler lasers measure vertical velocity of the road surface at points within the deflection bowl.
- Doesn't measure pavement deflection directly.

What to do with these measurements?

  - **DRD/Greenwood:** Beam model to convert measured TSD "slope" (V_V/V_H) v's offset into deflection bowl.
  - **TRL:** Monitor individual TSD "slope" values; correlate with Deflectograph.
  - **Muller & Roberts (2013):** Interpolate TSD slope measurements v's offset; numerical integration for deflection bowl

Interpretation of defection velocity



22nd ARRB Conference – Research into Practice, Canberra Australia, 2006

Table 1: Family of functions Proposed by ESGI

Bearing Capacity Characteristics derived from a Point Load F on an elastic beam with Elasticity E and thickness h. k is the spring constant of the foundation.

Deflection : $d(x) = -\frac{A}{2B}\left(\cos(Bx)+\sin(Bx)\right)e^{-Bx}$

Deflection Slope : $d'(x) = A\sin(Bx)e^{-Bx}$

Curvature : $d''(x) = AB\left(\cos(Bx)-\sin(Bx)\right)e^{-Bx}$

Elasticity : $E = \frac{3\sqrt{2}F}{4h^3}\cdot\frac{1}{AB^2}$

Stiffness : $k = \frac{\sqrt{2}F}{AB}$

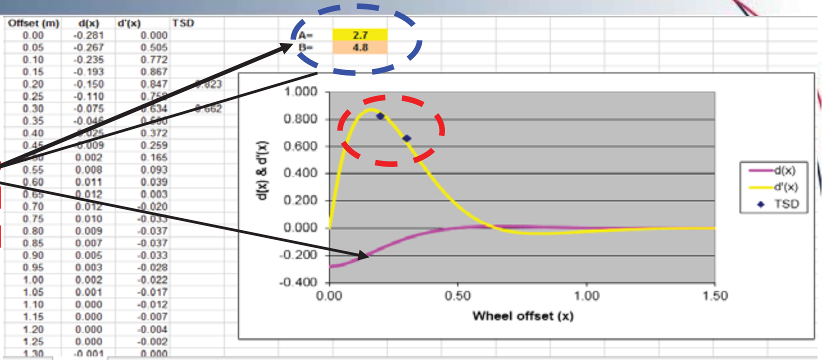
Maximum deflection : $d(0) = -\frac{A}{2B}$

Structural Curvature Index 300 : $\mathrm{SCI}_{300} = d(0) - d(300)$

Maximum Slope : $d'(\frac{\pi}{4B}) = \frac{e^{-\pi/4}}{\sqrt{2}}A$

Curvature under the wheel : $d''(0) = AB$

These functions are defined for x ≥ 0, A > 0 and B > 0. A and B are constants to be optimized.



Offset (m)	d(x)	d'(x)	TSD
0.00	-0.281	0.000	
0.05	-0.267	0.505	
0.10	-0.235	0.772	
0.15	-0.193	0.867	
0.20	-0.150	0.847	0.823
0.25	-0.110	0.758	
0.30	-0.075	0.634	0.662
0.35	-0.046	0.500	
0.40	-0.025	0.372	
0.45	-0.009	0.259	
0.50	0.002	0.165	
0.55	0.008	0.093	
0.60	0.011	0.039	
0.65	0.012	0.003	
0.70	0.012	-0.020	
0.75	0.010	-0.033	
0.80	0.009	-0.037	
0.85	0.007	-0.037	
0.90	0.005	-0.033	
0.95	0.003	-0.028	
1.00	0.002	-0.022	
1.05	0.001	-0.017	
1.10	0.000	-0.012	
1.15	0.000	-0.007	
1.20	0.000	-0.004	
1.25	0.000	-0.002	
1.30	-0.001	0.000	

A= 2.7
B= 4.8

Krarup, Rasmussen, Aagaard & Hjorth (2006):

- Optimise A & B for best fit of slope model to TSD measurements.
- Substitute into deflection eqn. for full bowl profile.

It works, but….

- Only two "levers" to fit models – often a poor fit to TSD slope data.
- Any particular model – okay at some locations, bad for others.
- Best to avoid using an explicit model altogether…

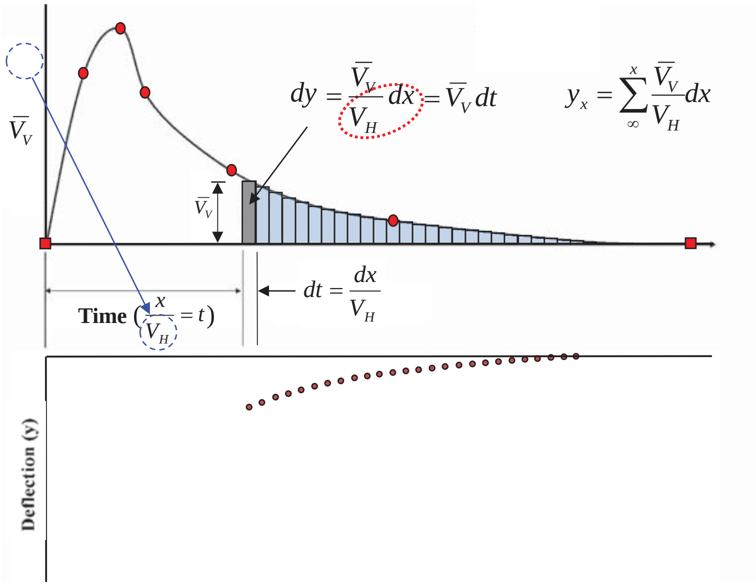
Interpretation of deflection velocity

Muller & Roberts (2012)/Area under the Curve Method:

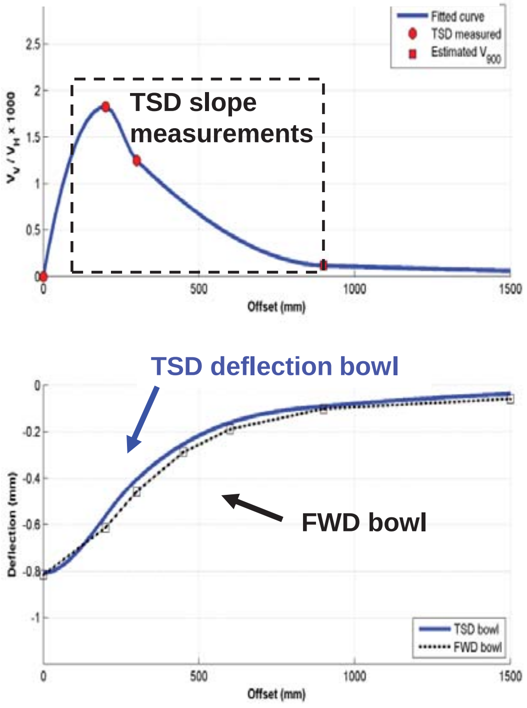
- Velocity is displacement over time
- TSD travelling in the horizontal *x-direction* at 72km/hr (20m/s).
- A single point on the ground 500mm ahead of wheel load.
- This point is deflecting with a vertical velocity (V_{500}) in the vertical *y-direction*.
- A short time later (*dt* = 1/1000th sec) the TSD has travelled horizontally by: $dx = 20mm$
- The point is now only 480mm from the wheel load.
- The vertical velocity of the point is now slightly different = V_{480}
- The average vertical velocity ($\bar{V}_V$) over the period *(dt)*: $\bar{V}_V = \frac{V_{480}+V_{500}}{2}$
- Same time period (*dt*), for vertical deflection (*dy*) & TSD displacement (*dx*): $dt = \frac{dy}{\bar{V}_V} = \frac{dx}{V_H}$
- Rearranging: $dy = \frac{\bar{V}_V}{V_H}dx$

Interpretation of deflection velocity

Plot velocities on V_V/V_H v's offset axes.
At 0m and 3.5m V_V is assumed to be 0
Curve fit between lasers and 0 points.
Area of each increment = contribution to deflection.
Add up increments for full deflection bowl.



Use on real TSD data

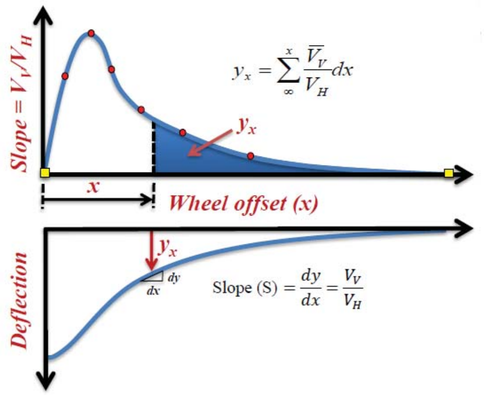


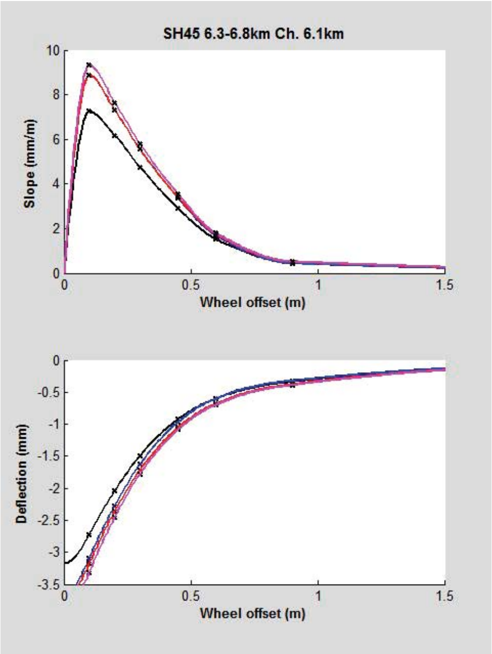
www.arrb.com.au

Data outputs AUTC

Area under the curve (AUTC) calculations

- TSD data calculated into a deflection bowl
- Deflections at any offset location
- Very good correlation to FWD data





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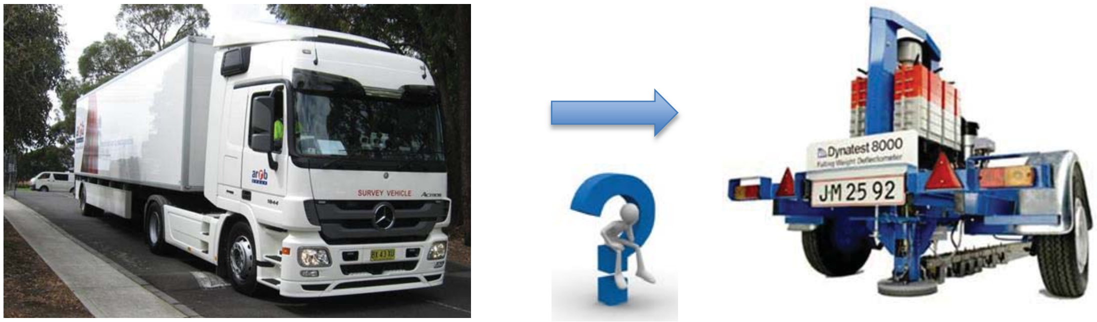
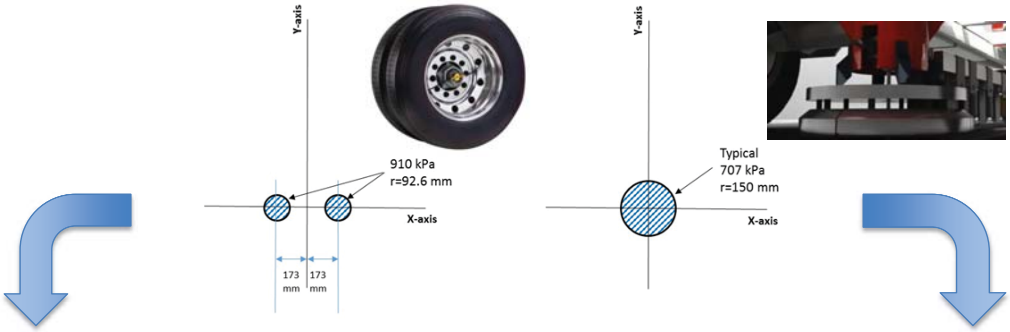
In Progress – TSD vs. FWD Research



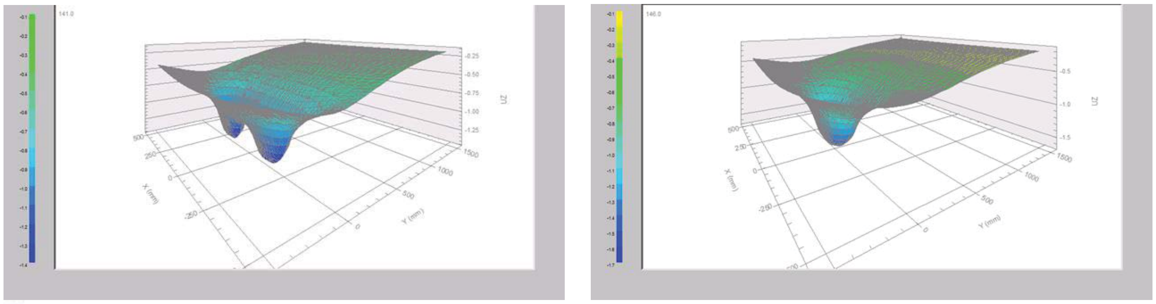
Correlation of TSD and FWD Deflections for a range of pavements:
- Granular pavements
- Stabilised pavement
- Full-depth asphalt pavements
- Concrete pavements

In Progress – TSD vs. FWD Research



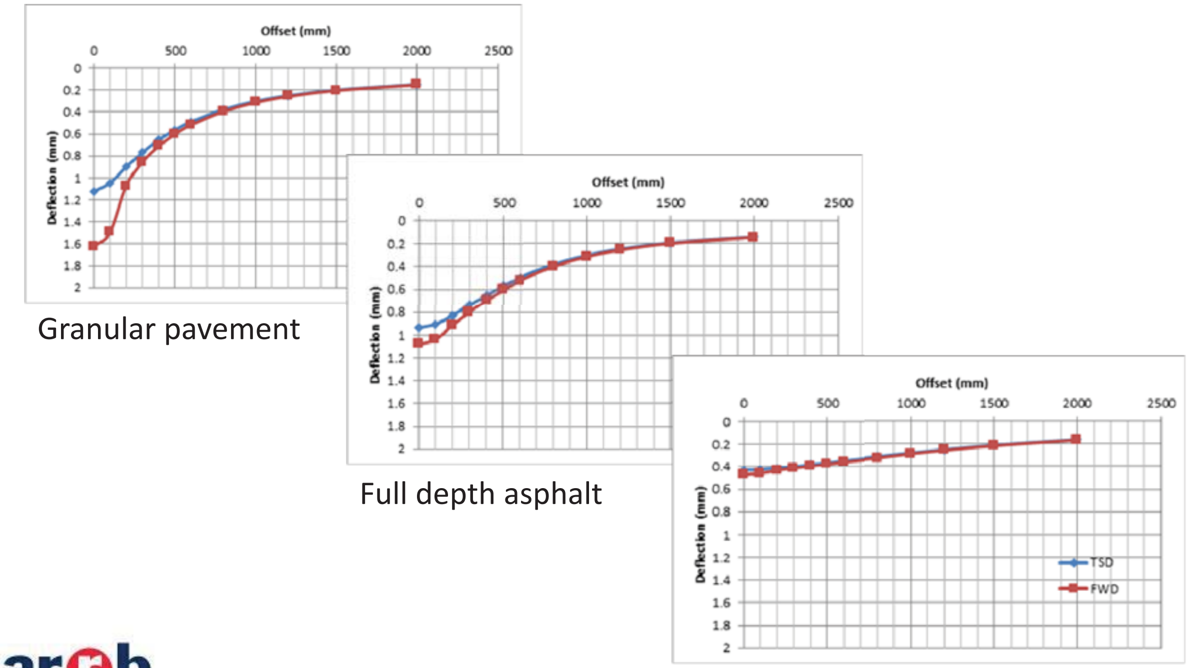
(a) Traffic speed deflectometer (half-dual axle)

(b) Falling weight deflectometer



In Progress – TSD vs. FWD Research

Theoretical computed deflection profile for different pavement types using CIRCLY

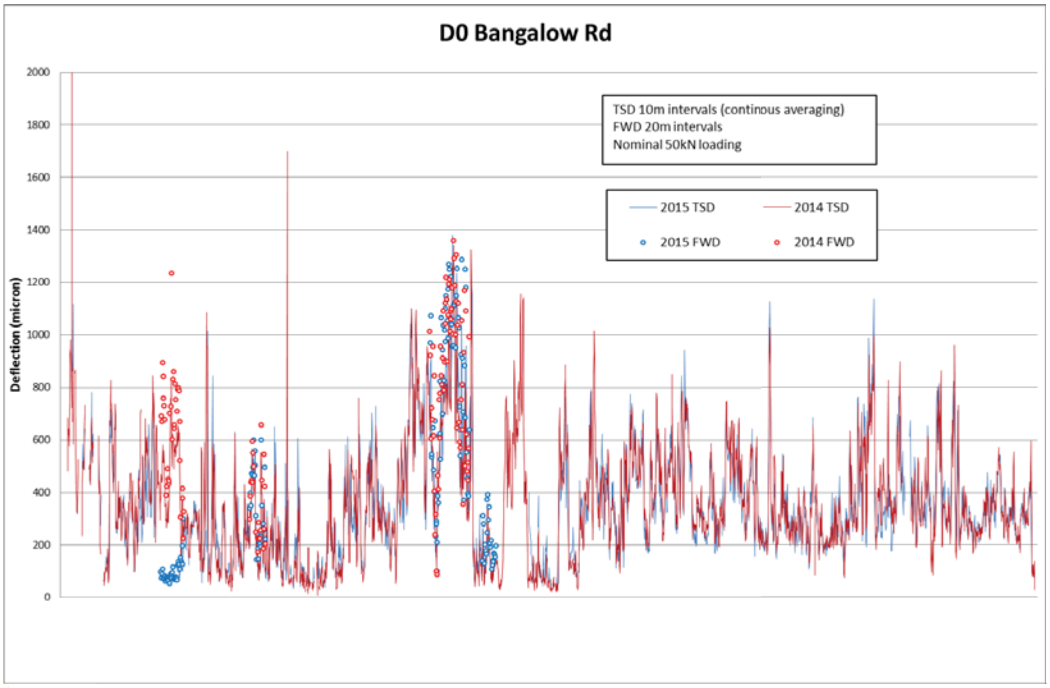


Granular pavement

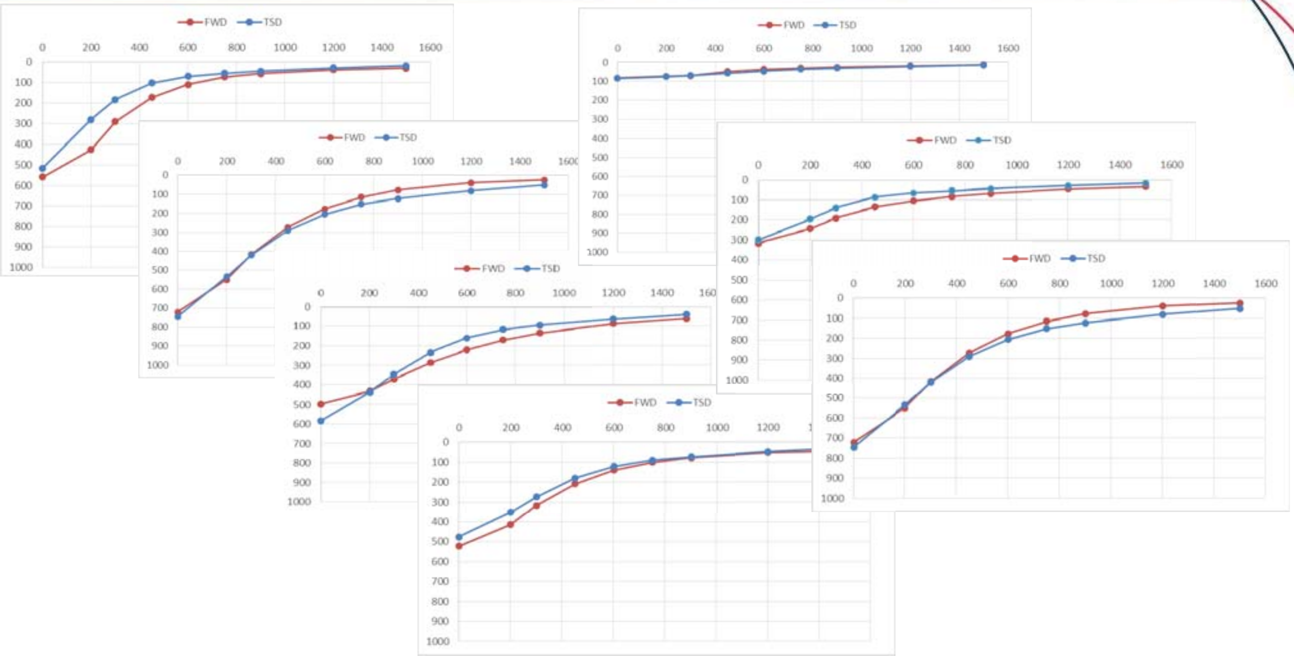
Full depth asphalt

Cement treated base

TSD vs. FWD trials

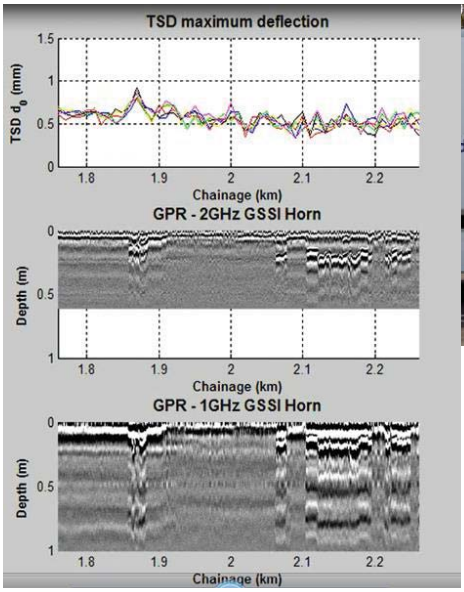


TSD vs. FWD trials



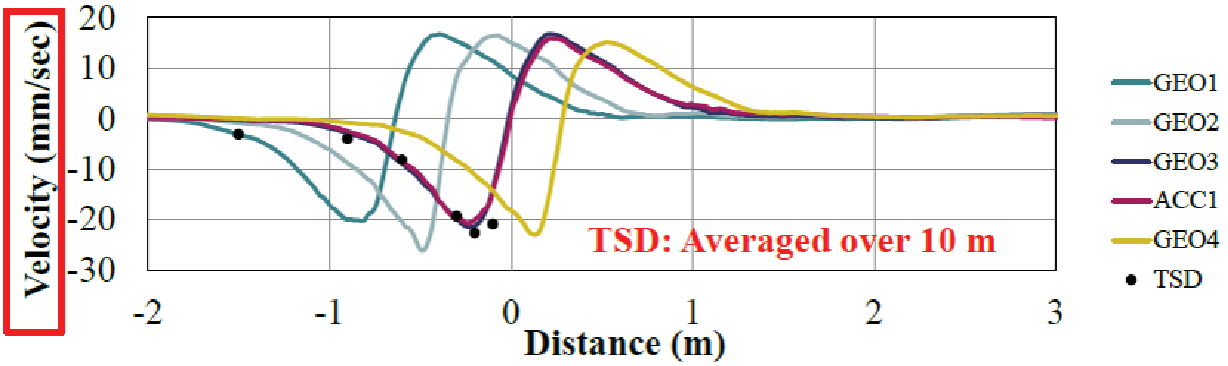
Future work - TSD GPR

- Integrated ground coupled GPR pod



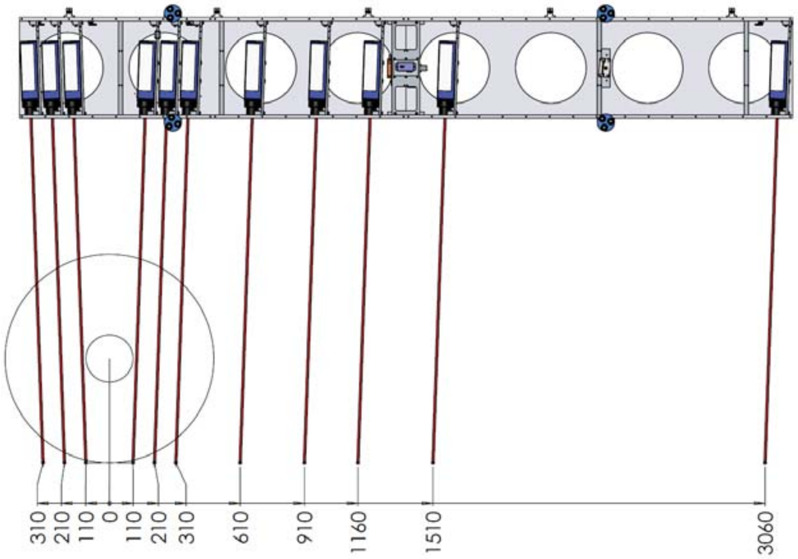
Future work - TSD Research

- Further FWD comparisons on other surface and pavement types
- Instrumented pavement surface transducers
  - “Ground Truth” TSD Doppler velocity readings
  - rolling and static deflection
  - dynamic pavement behaviour.



Future work – TSD

- Doppler laser calibration processes
- Behind the load measurements



Questions?

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January 14, 2016
Washington DC

TSD
Update from Greenwood

Jørgen Krarup

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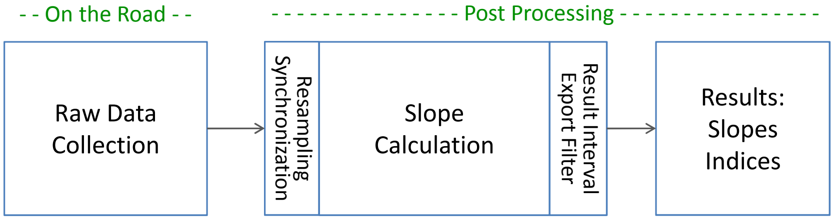
TSD Data Flow



- - On the Road - -

- - - - - - - - - - - - - - - Post Processing - - - - - - - - - - - - - - -

Raw Data Collection

Resampling Synchronization

Slope Calculation

Result Interval Export Filter

Results:
Slopes
Indices

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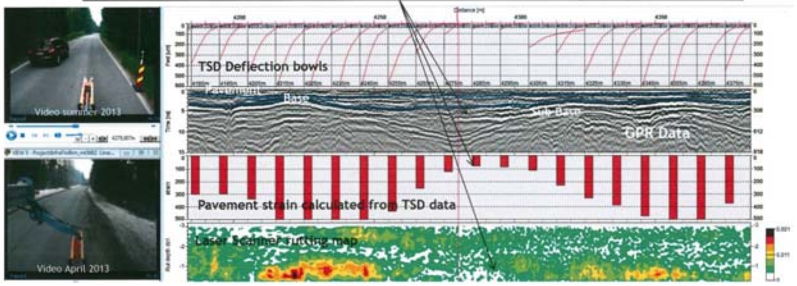
TSD + GPR in Finland

Example of a good road section where raising the grade line and new structures have succesfully reduced the deflections and pavement strain. Also rutting is minor in this new section. Strains increase immeaditely when entering ”old”section”.



ROADSCANNERS

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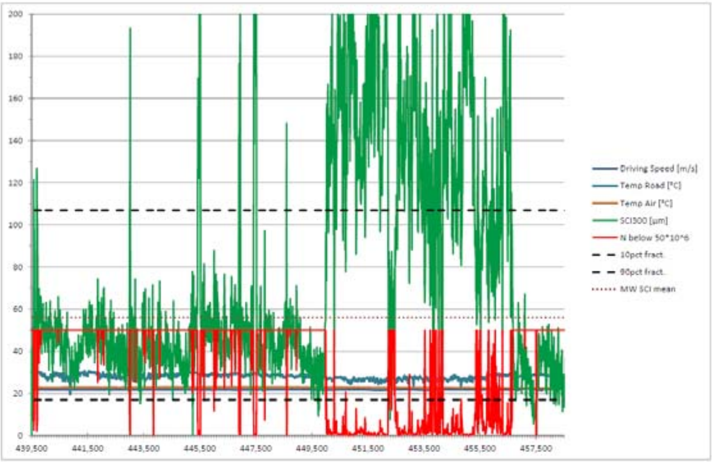
TSD in Greece June 2015



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1st and 2nd generation TSD sensor configuration

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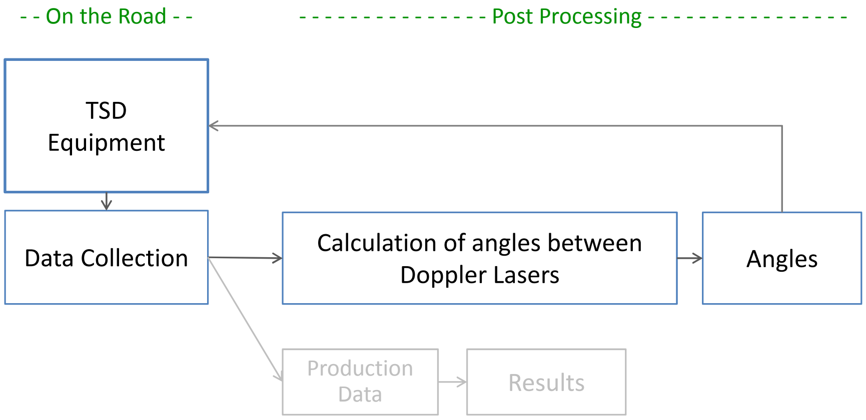
TSD Angle Calibration



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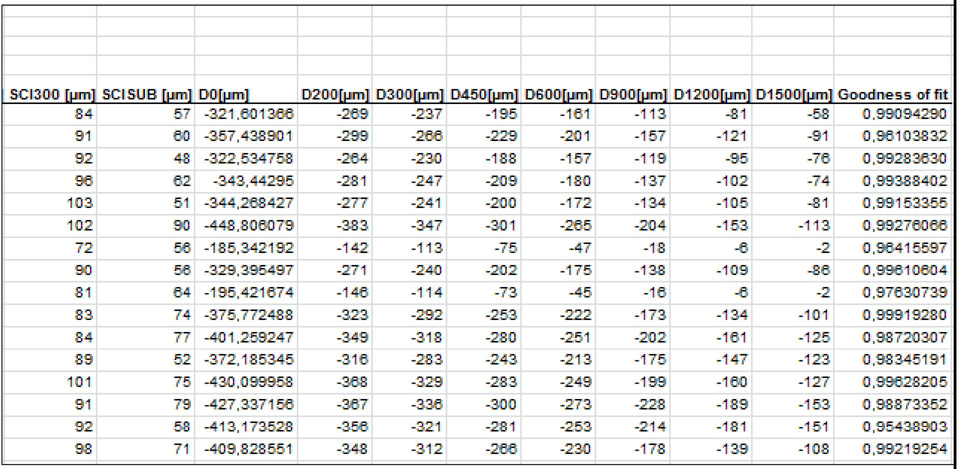
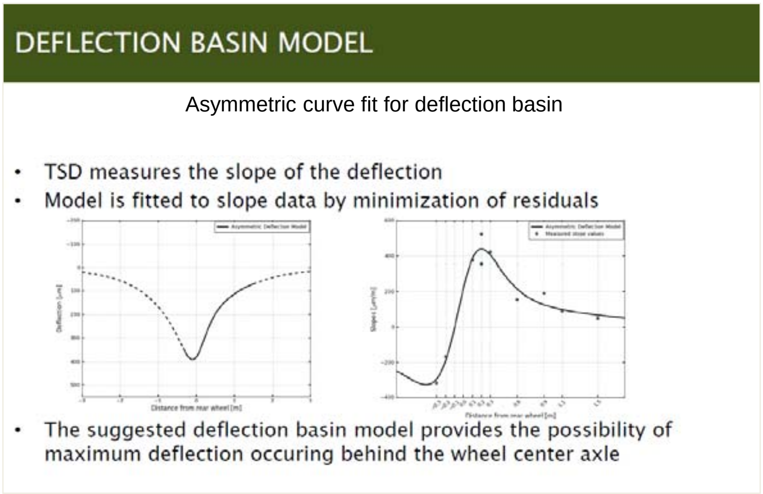
TSD result export example



SCI300 [μm]	SCISUB [μm]	D0[μm]	D200[μm]	D300[μm]	D450[μm]	D600[μm]	D900[μm]	D1200[μm]	D1500[μm]	Goodness of fit
84	57	-321,601366	-269	-237	-195	-161	-113	-81	-58	0,99094290
91	60	-357,438901	-299	-266	-229	-201	-157	-121	-91	0,96103832
92	48	-322,534758	-264	-230	-188	-157	-119	-95	-76	0,99283630
96	62	-343,44295	-281	-247	-209	-180	-137	-102	-74	0,99388402
103	51	-344,268427	-277	-241	-200	-172	-134	-105	-81	0,99153355
102	90	-448,806079	-383	-347	-301	-265	-204	-153	-113	0,99276066
72	56	-185,342192	-142	-113	-75	-47	-18	-6	-2	0,96415597
90	56	-329,395497	-271	-240	-202	-175	-138	-109	-86	0,99610604
81	64	-195,421674	-146	-114	-73	-45	-16	-6	-2	0,97630739
83	74	-375,772488	-323	-292	-253	-222	-173	-134	-101	0,99919280
84	77	-401,259247	-349	-318	-280	-251	-202	-161	-125	0,98720307
89	52	-372,185345	-316	-283	-243	-213	-175	-147	-123	0,98345191
101	75	-430,099958	-368	-329	-283	-249	-199	-160	-127	0,99628205
91	79	-427,337156	-367	-336	-300	-273	-228	-189	-153	0,98873352
92	58	-413,173528	-356	-321	-281	-253	-214	-181	-151	0,95438903
98	71	-409,828551	-348	-312	-266	-230	-178	-139	-108	0,99219254



DEFLECTION BASIN MODEL

Asymmetric curve fit for deflection basin

- TSD measures the slope of the deflection
- Model is fitted to slope data by minimization of residuals

- The suggested deflection basin model provides the possibility of maximum deflection occuring behind the wheel center axle

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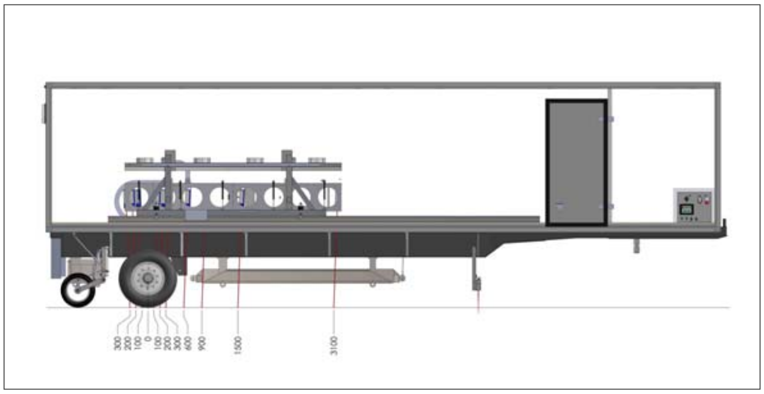
New configuration allows measuring points before and after axle-load



Elements from Factory Acceptance Test:

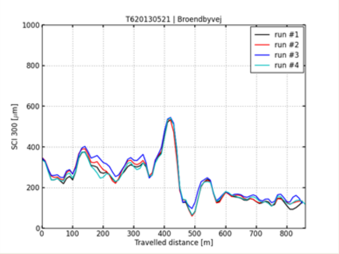
- **Commissioning Test – TSD6 – May 2013**

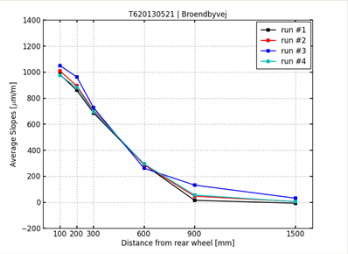
Upon completion of the Traffic Speed Deflectometer TSD6) test runs have been carried out.
Four test runs have been carried out at Brøndbyvej, Denmark with an average driving speed of 50 km/h.
During these test runs the load was 70% of the nominal weight.

- **Measurement results and Repeatability**

The SCI300 and the average slopes are shown in the two figures below.
Furthermore, Pearson’s correlation coefficients for the comparison between the four runs are indicated.

Runs	Correlation
#1 vs. #2	0.9996
#1 vs. #3	0.9931
#1 vs. #4	0.9995
#2 vs. #3	0.9960
#2 vs. #4	0.9998
#3 vs. #4	0.9957





Sept 2015, TSD-USA finalizing with the pooled fund project

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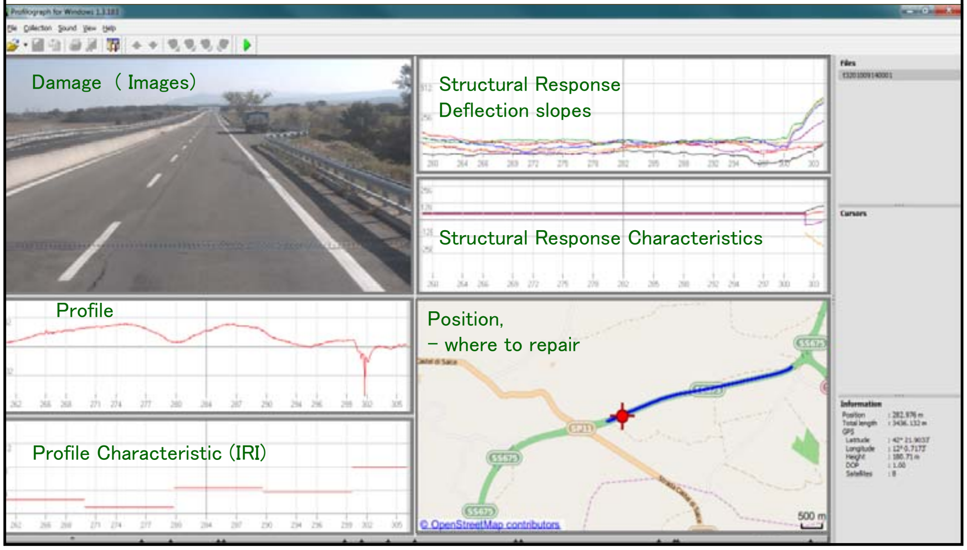
TAC4
January 14, 2016
Washington DC

Greenwood TSD
Output reporting

Jørgen Krarup

GREENWOOD ENGINEERING

What are we looking for ?



Damage (Images)

Structural Response
Deflection slopes

Structural Response Characteristics

Profile

Position,
– where to repair

Profile Characteristic (IRI)

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User selected windows + Deflection Basin

Information

Position : 588.625 m
Total length : 1575.719 m
GPS
Latitude : 39° 53.9658'
Longitude : 22° 36.8513'
Height : 21.01 m
DOP : 1.10
Satellites : 7

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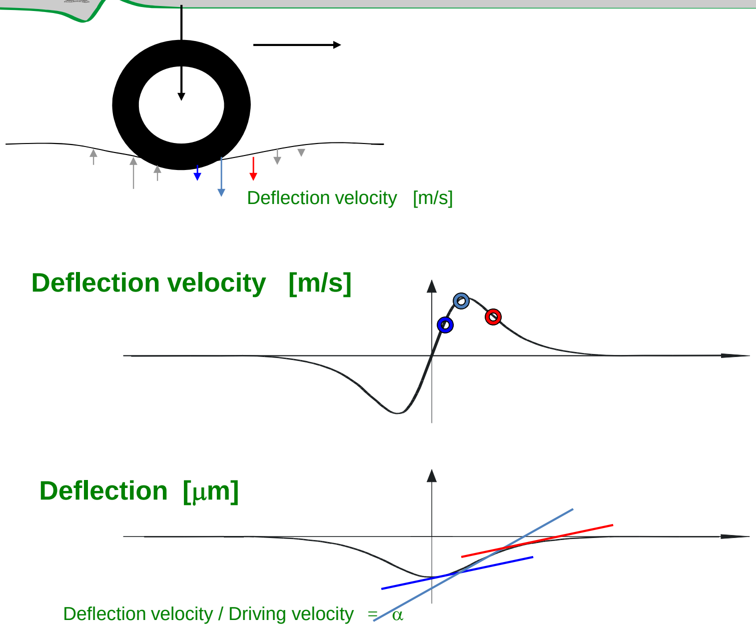

Deflection velocity [m/s]

Deflection velocity [m/s]

Deflection [µm]

Deflection velocity / Driving velocity = α

α = Deflection slope [µm/m]

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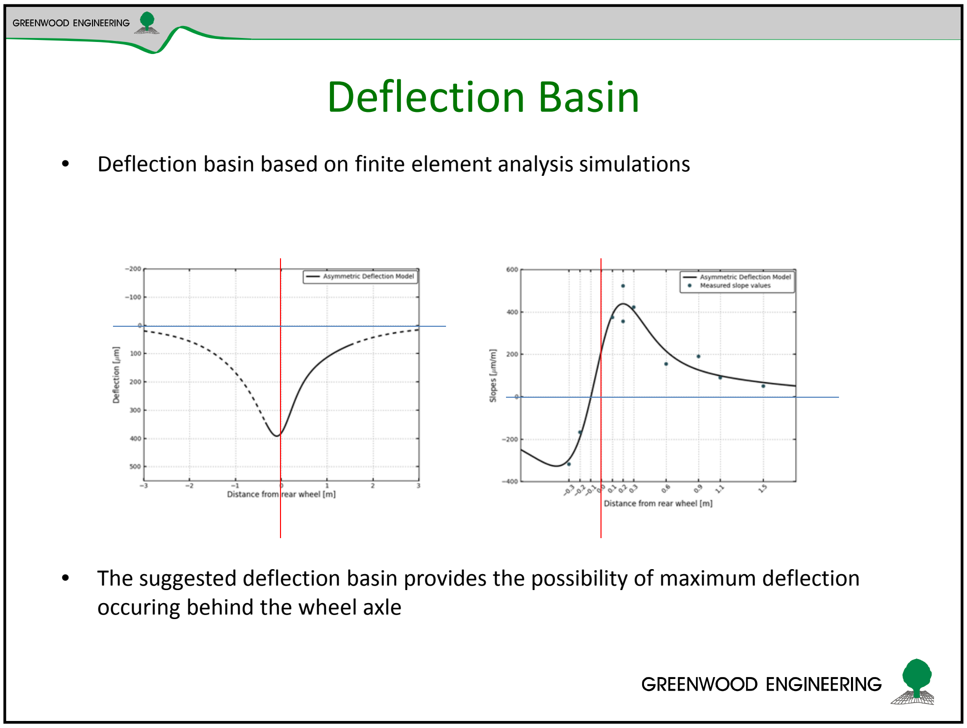

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Deflection Basin

- Deflection basin based on finite element analysis simulations

- The suggested deflection basin provides the possibility of maximum deflection occuring behind the wheel axle

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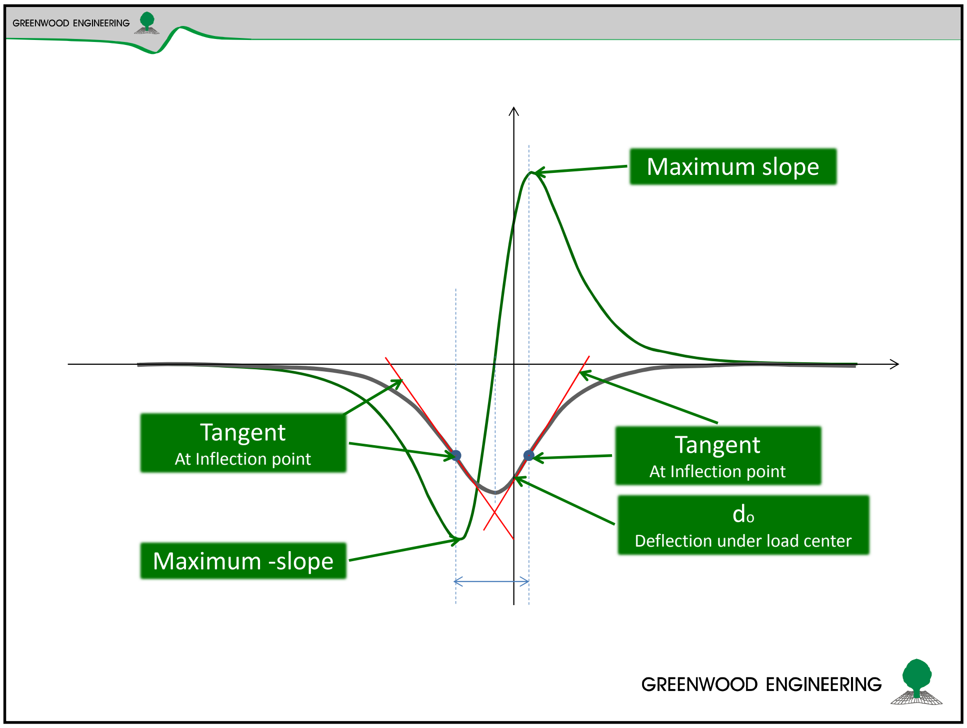

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Maximum slope

Tangent
At Inflection point

Tangent
At Inflection point

d_0
Deflection under load center

Maximum -slope

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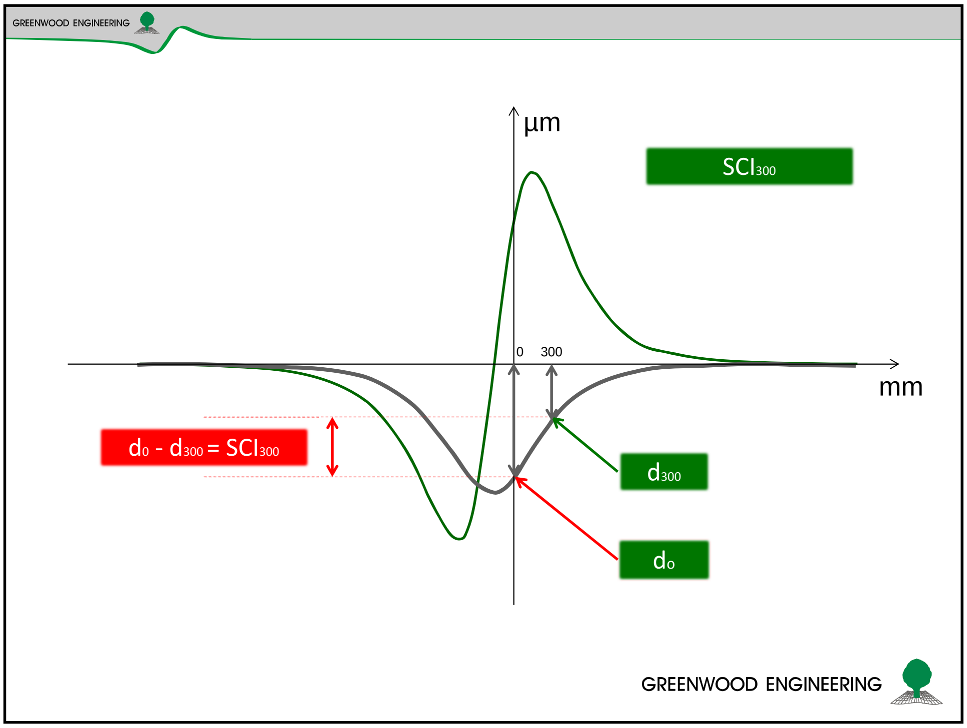

SCI$_{300}$

$d_0 - d_{300} = SCI_{300}$

d_{300}

d_0

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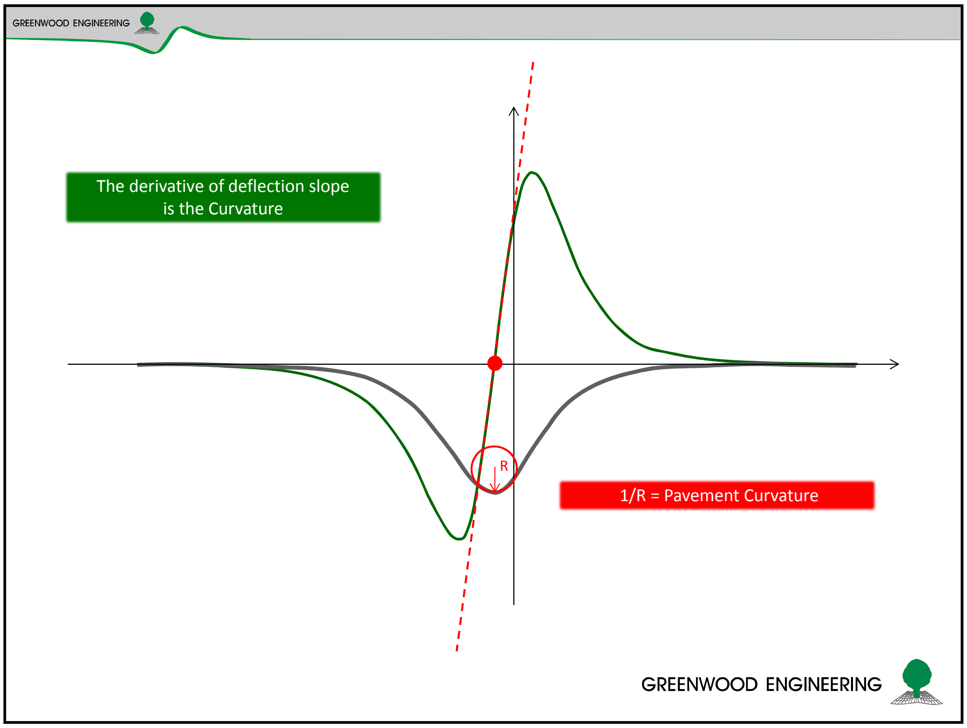

The derivative of deflection slope
is the Curvature

1/R = Pavement Curvature

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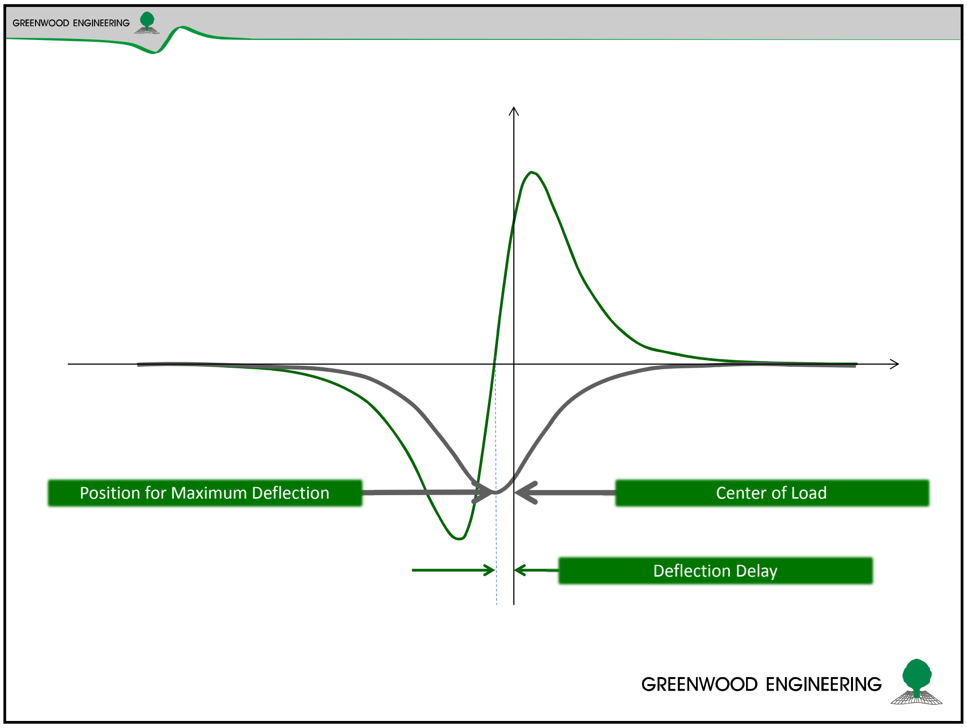


Position for Maximum Deflection

Center of Load

Deflection Delay

GREENWOOD ENGINEERING

Tak for opmærksomheden !

jk@greenwood.dk

Update on UK and European TSD issues

Brian Ferne, TRL

TAC4
TRB2016
Washington DC

14 January 2016

Contents

1. DaRTS4
2. European Projects
    1. BeCATS
    2. HiSPEQ
3. UK Deflection design method

DaRTS4

- Fourth meeting of **D**eflection **a**t **R**oad **T**raffic **S**peed Group
- Meeting held
  - At BAM headquarters, Berlin
  - On 18 September 2015
- Attended by 12 ‘members’ from
  - Denmark, Germany, France, Belgium
  - Spain, The Netherlands, the UK and Australia
- Plus 3 members on-line from Australia and the USA

DaRTS4

New attendees:

- Professor J. Stefan Bald – Technical University of Darmstadt
- Professor Hartmut Beckdahl – University of Wuppertal
- Gregers Hildebrand - COWI, Denmark representing HiSPEQ
- Steven Mookhoek – TNO Infrastructure representing RWS

DARTS4
AGENDA – PART 1

Updates from members on status of high-speed deflection devices (HSDD) and related projects

❑ Germany
  ❑ Dirk Jansen, BaST
  ❑ Professor. Beckdahl
  ❑ Professor Bald

❑ The Netherlands – RWS project – Steven Moorhoek

❑ UK – Brian Ferne

❑ Greenwood - Jorgen Krarup

DaRTS 4

Update from Germany on status of HSDD

Dr. Dirk Jansen

Bundesanstalt für Straßenwesen BASt
Federal Highway Research Institute

TSD evaluation

Project overview

1st generation TSD

- 2006: Measurements on BASt indoor test road
- 2008: Measurements on different in situ pavements

2nd generation TSD

- 2012: 300 km of measurements on different pavements
- 2014: 50 km comparative measurements on highway section
- 2015: Start of R&D project – focus: repeatability
- 2016: Purchase of multifunctional TSD

Assessment procedures

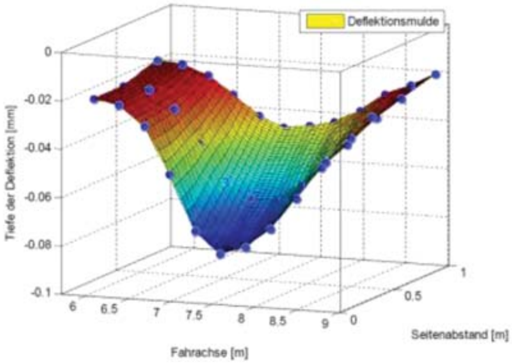
- In-Motion Project (RWTH by order of BASt 'Innovation Program')

Assessment

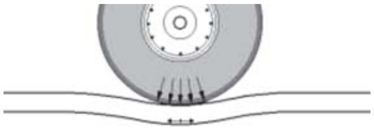
Project In-Motion

Measuring

Modeling



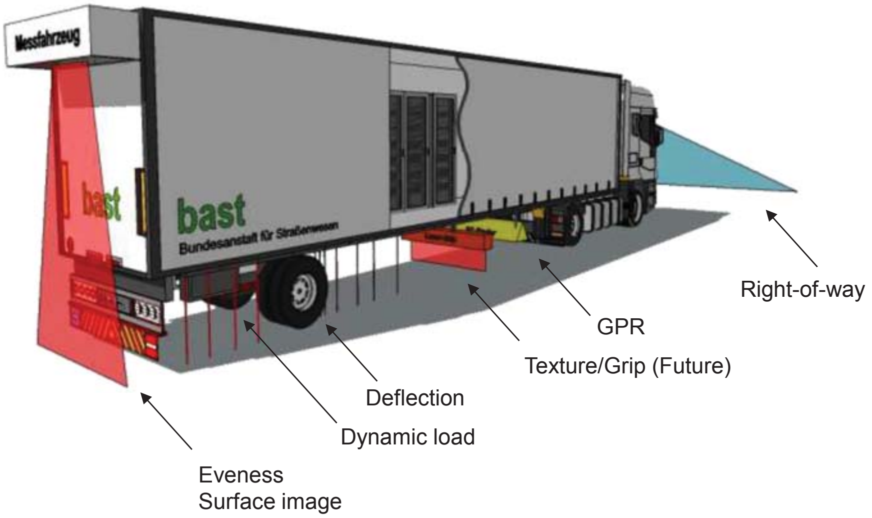
Calculation of strains (FEM)



Assessment of residual lifetime

BASt multifunctional TSD

MESAS – Multifunktionales Erfassungssystem zur Substanzbewertung und zum Aufbau von Straßen
Multifunktional assessment tool for the structural evaluation and the design of pavements



Application for funding A Traffic Speed Deflectometer (TSD) in Germany
German Research Foundation
Deutsche Forschungsgemeinschaft (DFG)

Professor Beckdahl – University of Wuppertal

B

Federal Highway Research Institute

The funding of Scientific Equipment is a part of the DFG's major research instrumentation programme

Purpose of Funding

1. The DFG funds large (expensive) scientific equipment.
2. Financing is provided in equal parts by the DFG ➔ F R GER and the university's home state
   (50% DFG, 40% NRW, 9% BESTLAB , 1% BUW).
3. Proposed research instrumentation project must be of high quality and national importance.
4. The instrumentation has to be used for research only and may also be used in teaching.

5th conference

Transport Solutions:
from Research to Deployment
Innovate Mobility, Mobilise Innovation!
Paris - La Défense CNIT, 14 - 17 April 2014

Evaluation of Load-Carrying Capacity of Asphalt Superstructures from Deflection Measurements

J. Stefan Bald, Prof. Dr.-Ing., Technische Universitaet Darmstadt, Germany

- *jsbald@sw.tu-darmstadt.de*

Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

Research Programme Replacement & Renovation Pavements

Steven Mookhoek (TNO)

Ministry of Infrastructure and Environment

The Netherlands

Introduction:

- Large fraction of the Dutch motorway network was constructed in 1960-1970s. Pavement area increased from 20% to 80% of its current area!
- Past philosophy: with right maintenance and reinforcement strategy life expectancy = indefinite...?!
- Information on BC only when large renovation 15-17 years is performed
- Identified risks:
  - Only limited information available of real effects of maintenance and used materials in last 50 years on bearing capacity/integrity of the road network
  - Limited information on culverts <1.5 m in diameter in the roads
  - Not traffic/climate changes taken into account on pavement and road design

Research Programme Replacement & Renovation Pavements 2016-2020

Aim

Risk assessment and R&R needs by 2020 of pavements on Dutch road network

- 2015 Set-up of Research Programme R&R pavements
- 2016 Determining data sources, suitable inspection and measurement methods
- 2017 Start inventory of pavement characteristics and gathering information through inspection and measurements
- 2018 Start analysis and recommendations replacements/renovations

---

Status on the UK use of the TSD

Brian Ferne, TRL

Current status of TRASS3

Current and planned surveys

Main line Surveys

- Around 6000 km in 2014
- Around 6100 km in 2015
- As yet no routine GPR Surveys will start in 2016
- Some issues over data quality revealed by QA process

Slip road surveys

- This required definition of deceleration limits
- 1 m/s/s limit embodied in validation software
- Around 2500km of slip roads covered so far in 2015/6 but 20% failed validation

Outer lane surveys

- Outer lane or passing/fast lane not generally used by heavy goods vehicles
- This required official procedure for surveying and permitting undertaking
- Interim Advice Note drafted
- No surveys yet except under police guidance

Current use of TSD data in the UK

Usage of TRASS data stored in PMS

Reducing other surveys

- Deflection slopes converted to network structural condition categories 1 to 4
- Categories used to guide scheme selection
- Categories used to guide type of further investigation
- Categories 1 and 2 suggest less need for slow speed disruptive investigations

SMART motorways

- This mainly involves conversion of hard shoulder to part-time running lane
- TSD surveys can provide guidance on strengthening need or otherwise

Surfacing Schemes

- Central decision in England to resurface 80% of HE network
- Impossible for HE engineers to directly approve all proposals
- Simplified approval process developed based on TSD structural condition categories

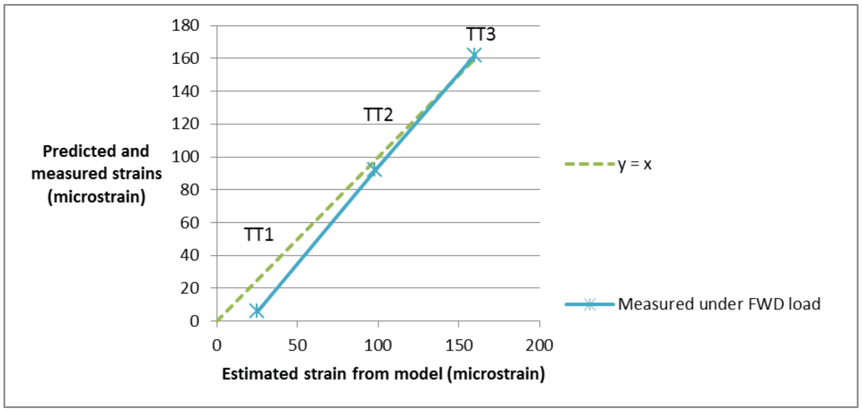
Future of TSD in the UK

- Under the TRASS contract the HE TSD will restart network surveys in Spring 2016 following major maintenance of the TSD

- TRL is currently commissioned by HE to consider their strategy for future structural survey needs, i.e. the format of TRASS4 if required.

- TRL will consider:
  - Worldwide developments in HSDDs
  - Recent TRL research with the TSD including
    - Comparative trials of 1st and 2nd generation TSDs
  - Experience with TRASS 1, 2 and 3 survey contracts

Future of deflection interpretation in the UK?
Estimation of strains from deflection
Measurement in test sections



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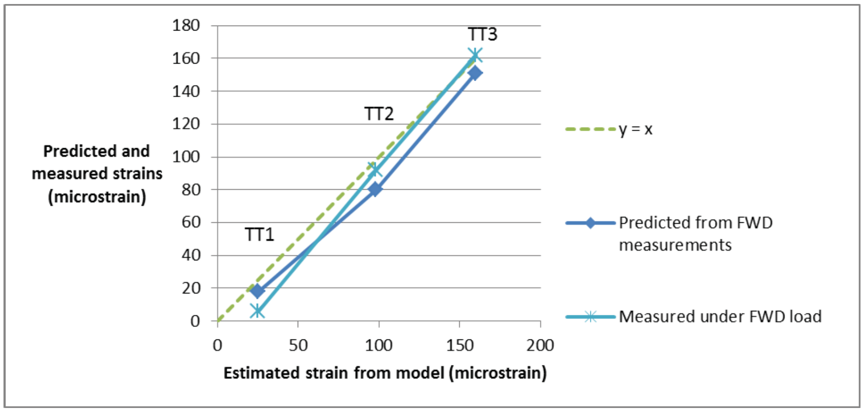
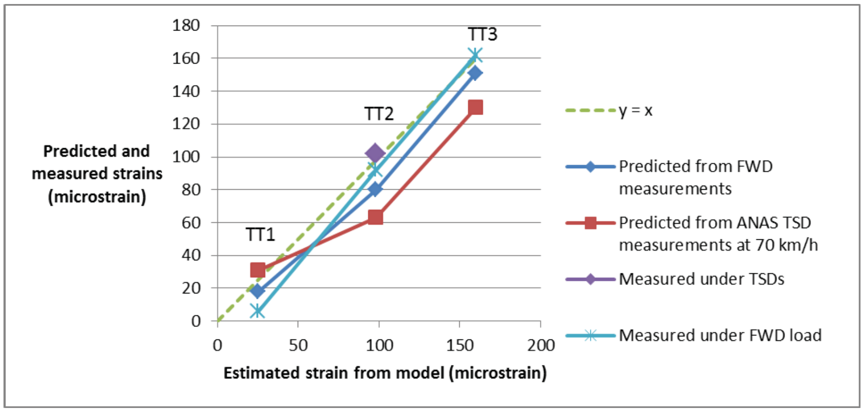
Prediction from FWD bowls



Future of deflection interpretation in the UK?
Estimation of strains from deflection
Prediction from TSD bowls



DARTS4
AGENDA – PART 2

Update on relevant European Groups and Projects including:

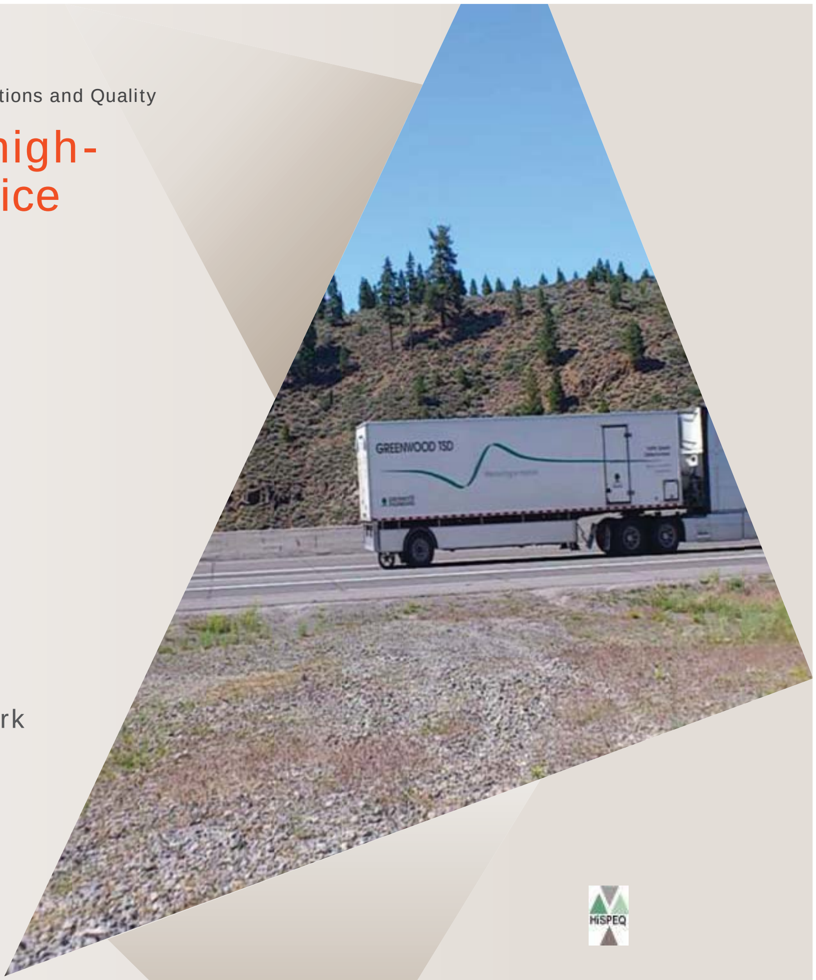
- BeCaTS - Brian Ferne on behalf of Adam Zofka
- HiSPEQ – Gregers Hildebrand
- Discussion
  - Comparison between deflection devices
  - Standardisation of deflection terms

HI-SPEQ –European project sponsored by CEDR

- **H**i-speed survey **SP**ecifications, **E**xplanation and **Q**uality
- Commissioned under the CEDR Ageing Infrastructure Management Call – High-speed non-destructive Condition Assessment. Managed by Ireland National Roads Authority
- 6 project partners (TRL, AIT, VTI, ZAG, COWI, Fugro). Start date 14th April 2014, Duration: 24 months. Led by TRL.
- HI-SPEQ will draw on a **Reference Group** of road owners & operators, ***survey equipment builders & users***, Data users, researchers etc.

HiSPEQ: Hi-speed survey Specifications, Explanations and Quality

Requirements for a high-speed deflection device



Gregers Hildebrand, COWI, Denmark
grhi@cowi.dk

Today's message

HiSPEQ aims at providing **guidance** to NRAs that will tender pavement condition testing. We will help the NRAs **understand** and **specify survey requirements, quality regimes and processing procedures**.

HiSPEQ focuses on **high-speed** testing devices and data for Pavement/Asset Management.

Today, focus is on the TSD.

Templates for measurement and equipment specs

- Two sets of templates:
  - Specification for testing
  - Equipment
  - Guidance documents for both templates

Testing specification templates

- HiSPEQ1: Specification for pavement condition measurement
- HiSPEQ2: Specification for referencing data to the network
- HiSPEQ3: Specification for pavement transverse evenness measurement
- HiSPEQ4: Specification for longitudinal unevenness measurement
- HiSPEQ5: Specification for pavement surface deterioration measurement
- HiSPEQ6: Specification for pavement structure measurement
- **HiSPEQ7: Specification for traffic speed pavement deflection surveys**

Equipment specification templates

- HiSPEQ2E: Equipment for location and network referencing
- HiSPEQ3E: Equipment for measurement of pavement transverse evenness
- HiSPEQ4E: Equipment for measurement of pavement longitudinal unevenness
- HiSPEQ5E: Equipment for pavement surface deterioration measurement
- HiSPEQ6E: Equipment for pavement layer measurement
- **HiSPEQ7E: Equipment for pavement deflection measurement**

Conclusions

We are in the process of producing guidelines to help NRAs – and others specify and hence tender TSD and other pavement tests.

We still need work on

- Parameters – data processing, combined use of TSD and GPR et al.
- Accreditation
- Quality assurance

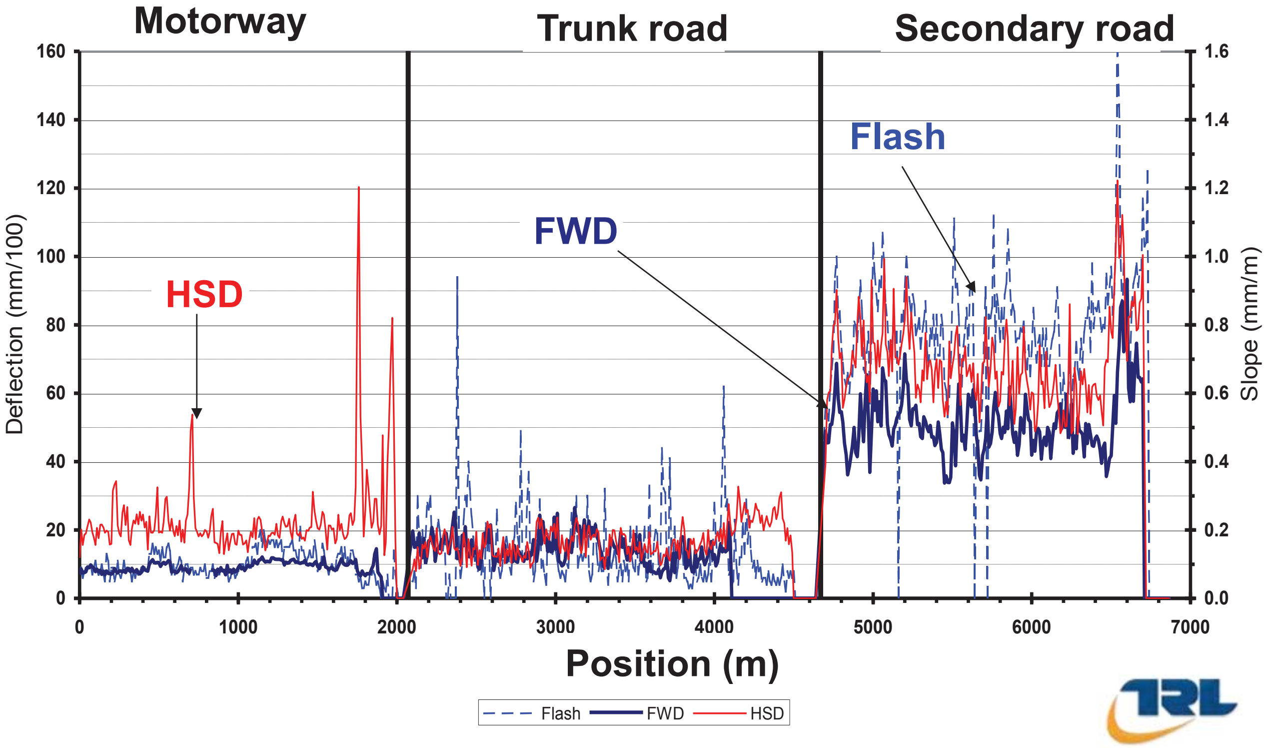
www.hispeq.com

DARTS4
AGENDA – PART 2

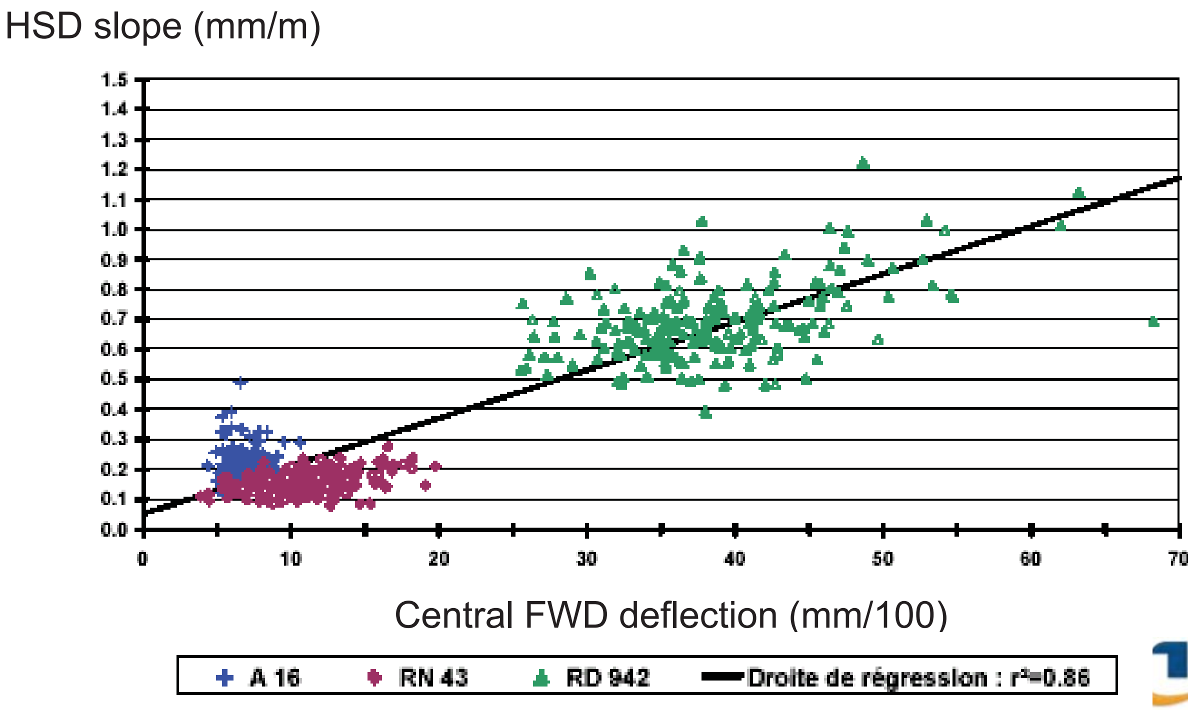
Update on relevant European Groups and Projects including:

- BeCaTS - Brian Ferne on behalf of Adam Zofka
- HiSPEQ – Gregers Hildebrand
- Discussion
  - Comparison between deflection devices
  - Standardisation of deflection terms

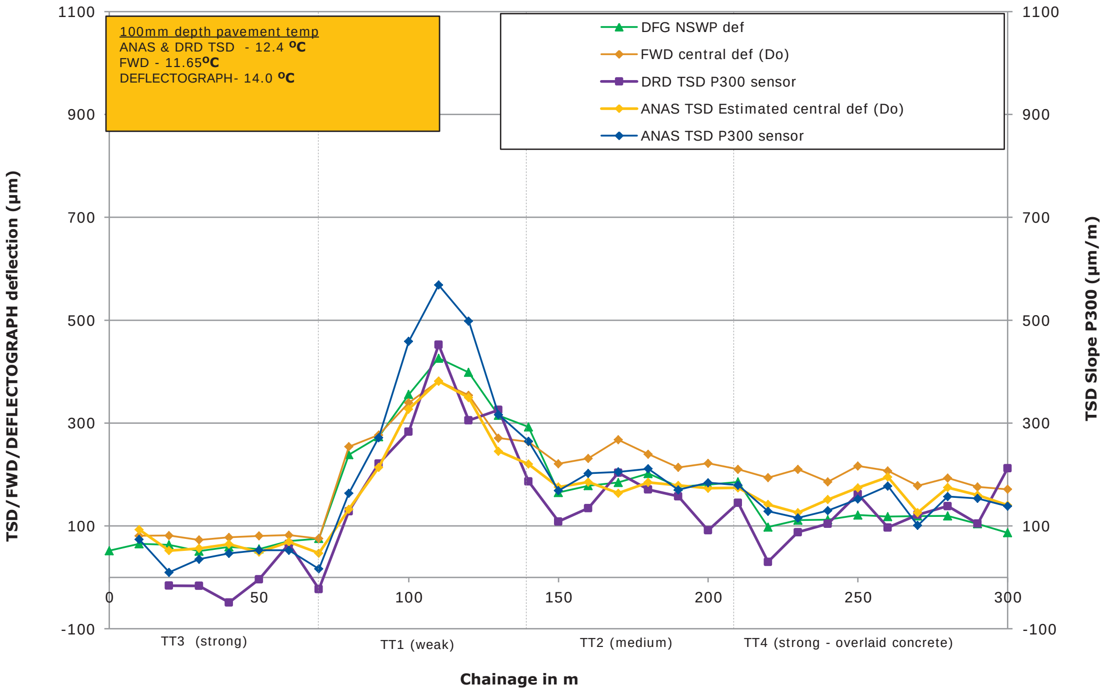
Comparison between HSD, Flash and FWD on three sites in France



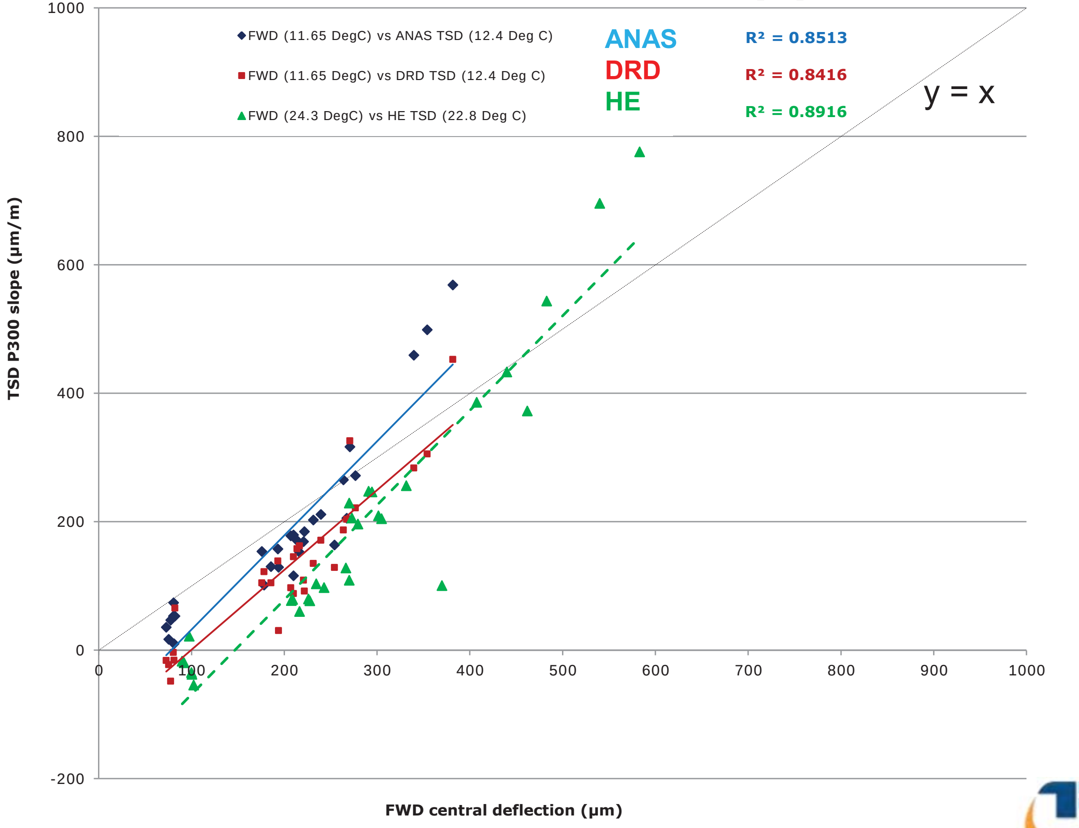
Correlation between HSD and FWD on three sites in France



Comparisons between deflections measured by different devices on UK test site (1)

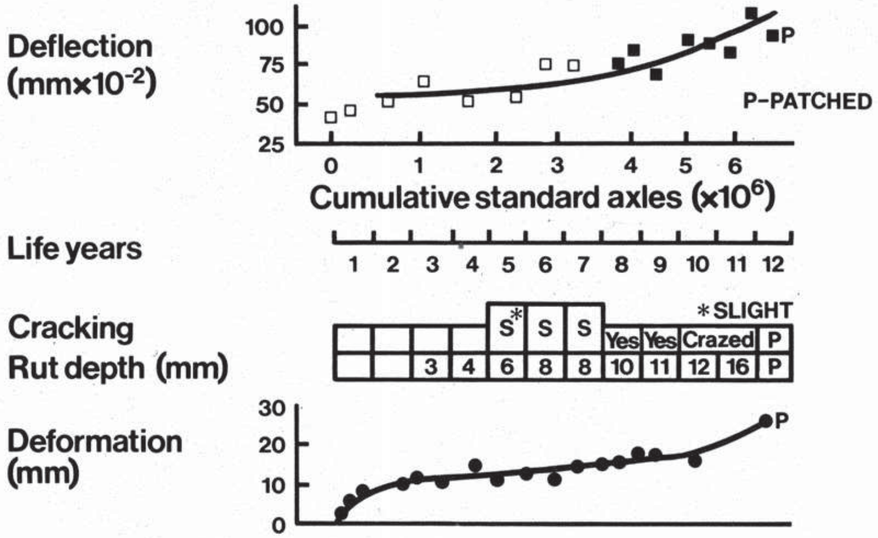


Comparisons between deflections measured by different devices on UK test site (2)



Development of the UK Deflection Design Method And its use with the TSD

COMPARISON OF DEFLECTION HISTORY, VISUAL CONDITION, AND PERMANENT DEFORMATION BEHAVIOUR

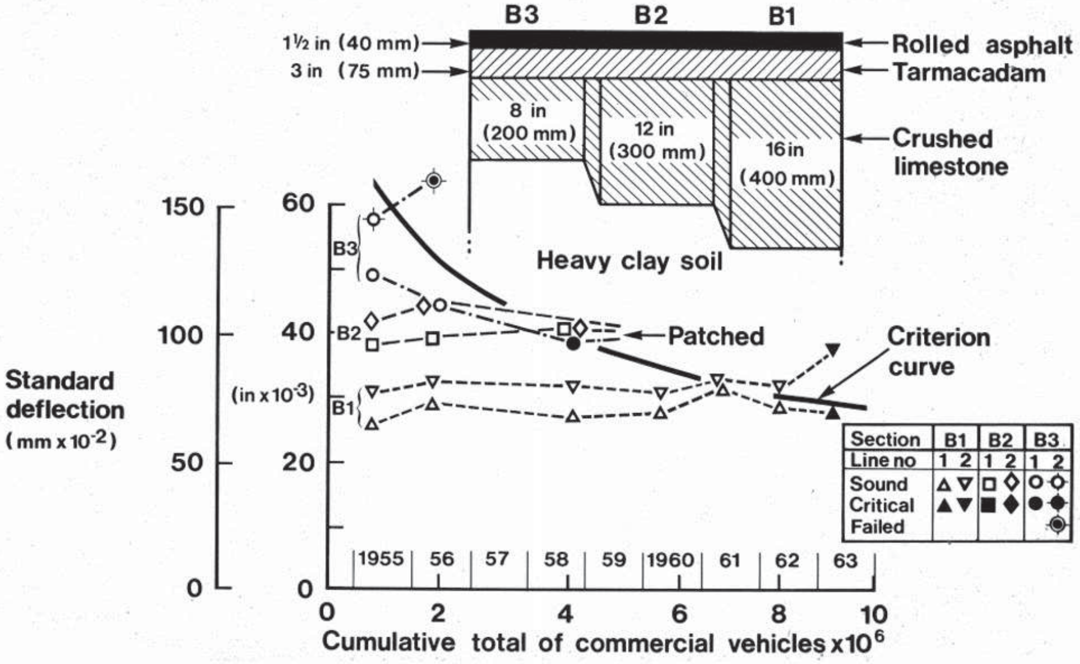


Life years	1	2	3	4	5	6	7	8	9	10	11	12
Cracking					S*	S	S	Yes	Yes	Crazed		P
Rut depth (mm)			3	4	6	8	8	10	11	12	16	P

*SLIGHT

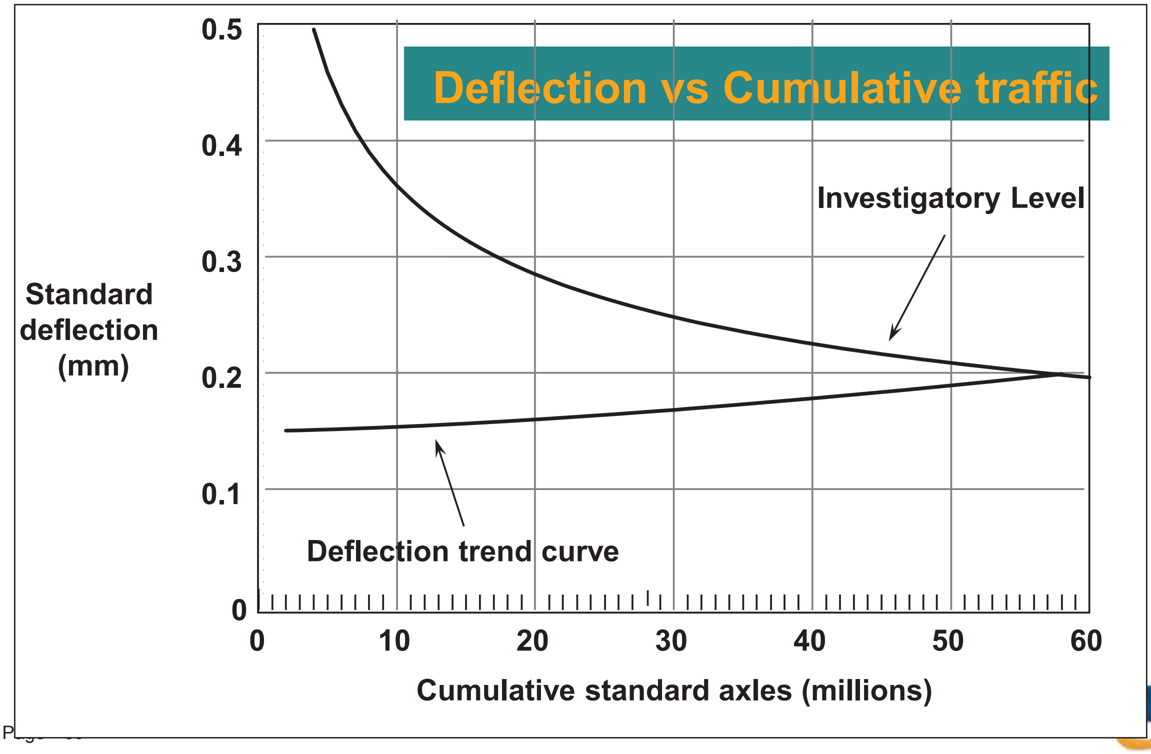
Section with rolled asphalt base

DEFLECTION HISTORY OF THREE EXPERIMENTAL SECTIONS AT CAMBRIDGE (GLOS) A38

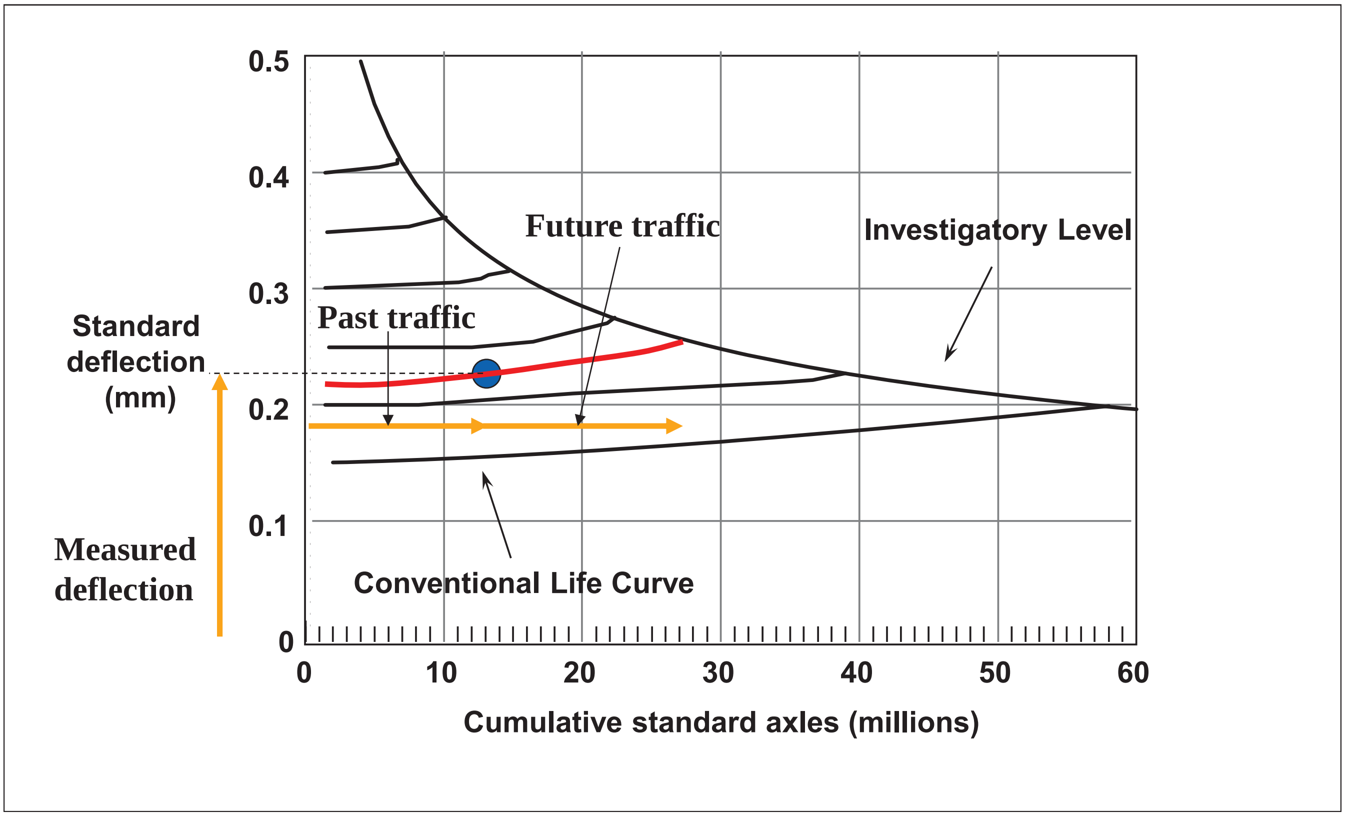


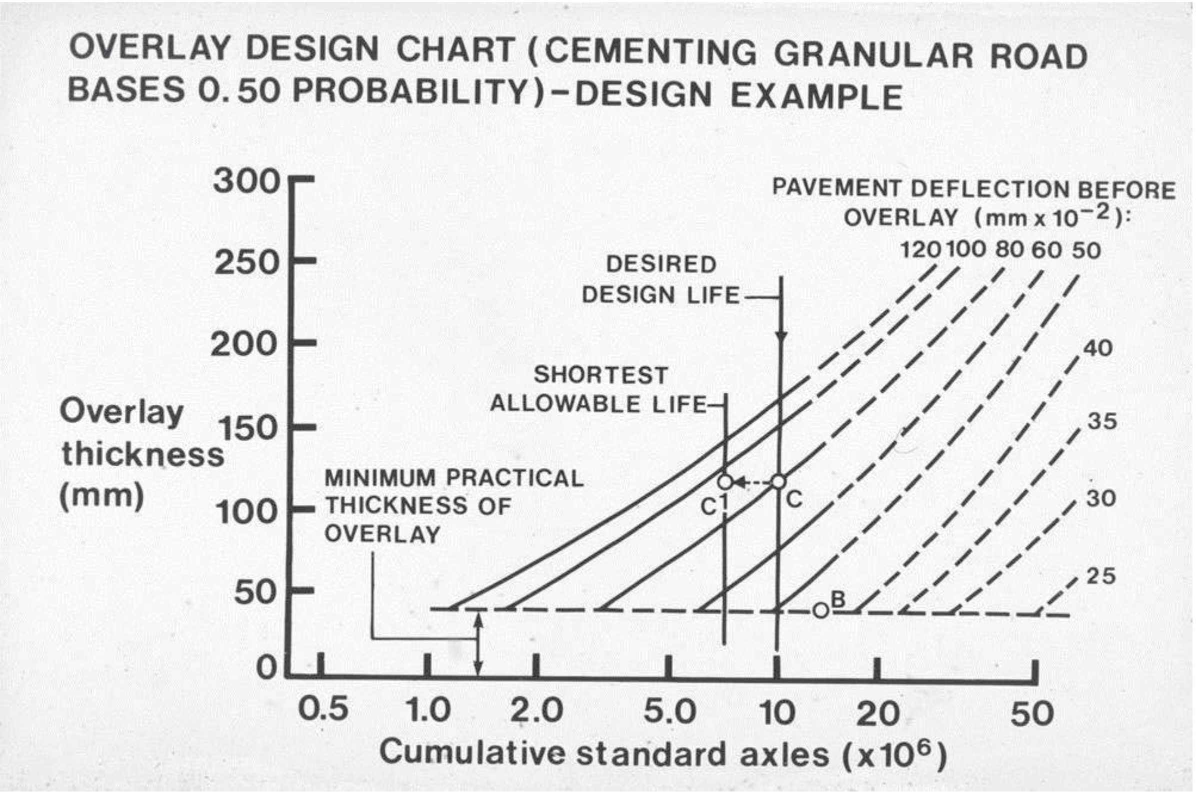
Section	B1		B2		B3	
Line no	1	2	1	2	1	2
Sound	△	▽	□	◇	○	⌖
Critical	▲	▼	■	◆	●	⯁
Failed						◉

Interpretation of deflection data in UK

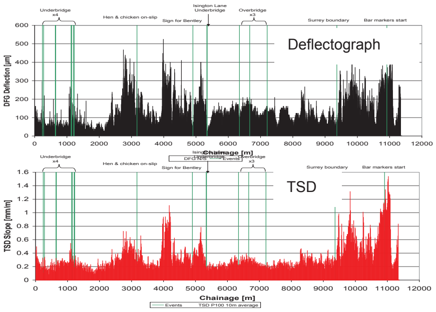


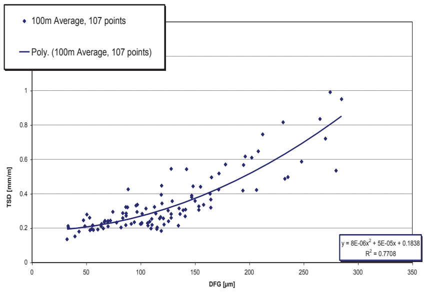
Interpretation of deflection data in UK - example




OVERLAY DESIGN CHART (CEMENTING GRANULAR ROAD BASES 0.50 PROBABILITY)-DESIGN EXAMPLE

TSD Development 2006-2009



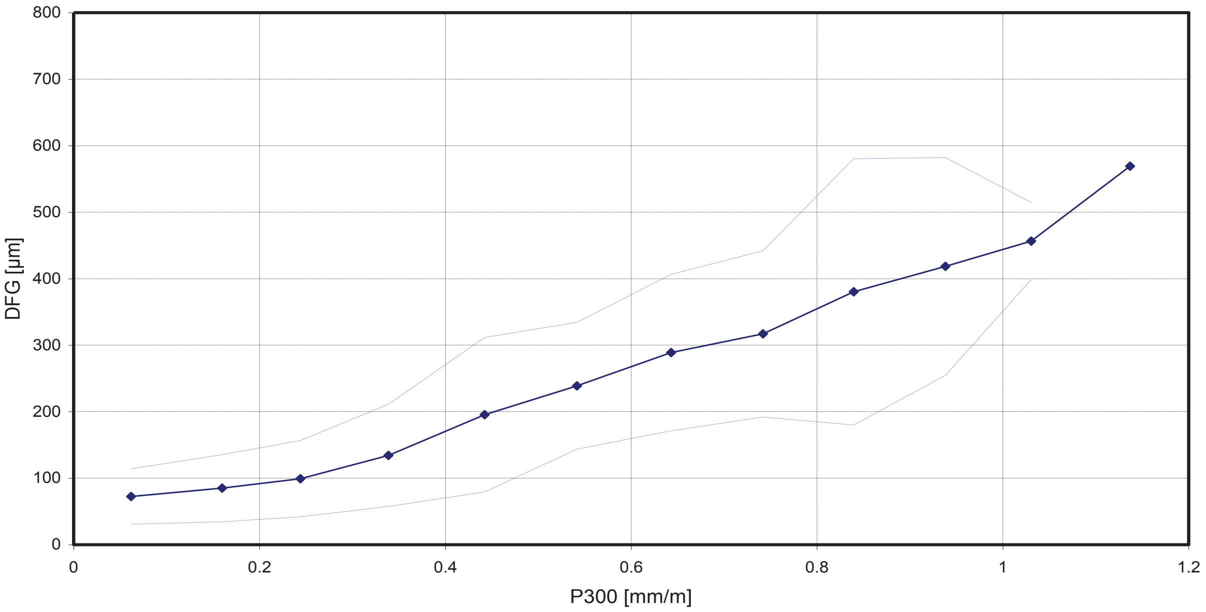


Development of prototype into fully functional research tool

Development of empirical relationship between TSD and Deflectograph

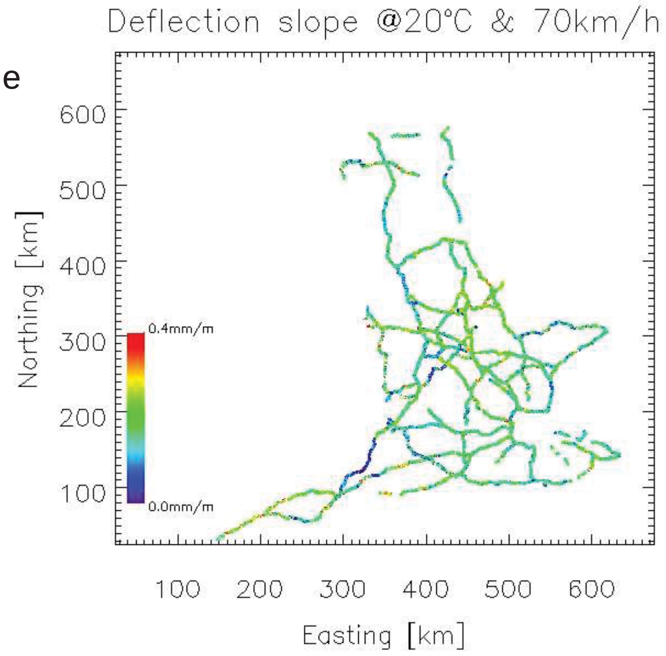
Ready for roll-out of network-level structural condition surveys as proxy for Deflectograph

Comparison with other deflection devices
- Sensor P300 v. Deflectograph



TRASS1&2 Summary

- The HA TSD was successfully developed into a system capable of delivering routine network level surveys
- Over 18000km of structural condition information was collected by TRASS1 and TRASS2
- Robust QA regime established
- HA Managing Agents could be provided with indicator of network level structural condition…..



TSD Network Structural Condition categories

Category	Description
1	Flexible pavements **without any need** for structural maintenance
2	Flexible pavements **unlikely to need** structural maintenance
3	Flexible pavements **likely to need** structural maintenance
4	Flexible pavements **very likely to need** structural maintenance

- If **all** the NSC categories for a scheme are 1 or 2 then a Deflectograph survey **is only required if** there is clear additional evidence of structural deterioration (eg longitudinal wheel-track cracking, pumping or settlement).
- If a scheme has no TSD data or has any length in NSC categories of 3 or 4 then a Deflectograph survey is required for the whole scheme

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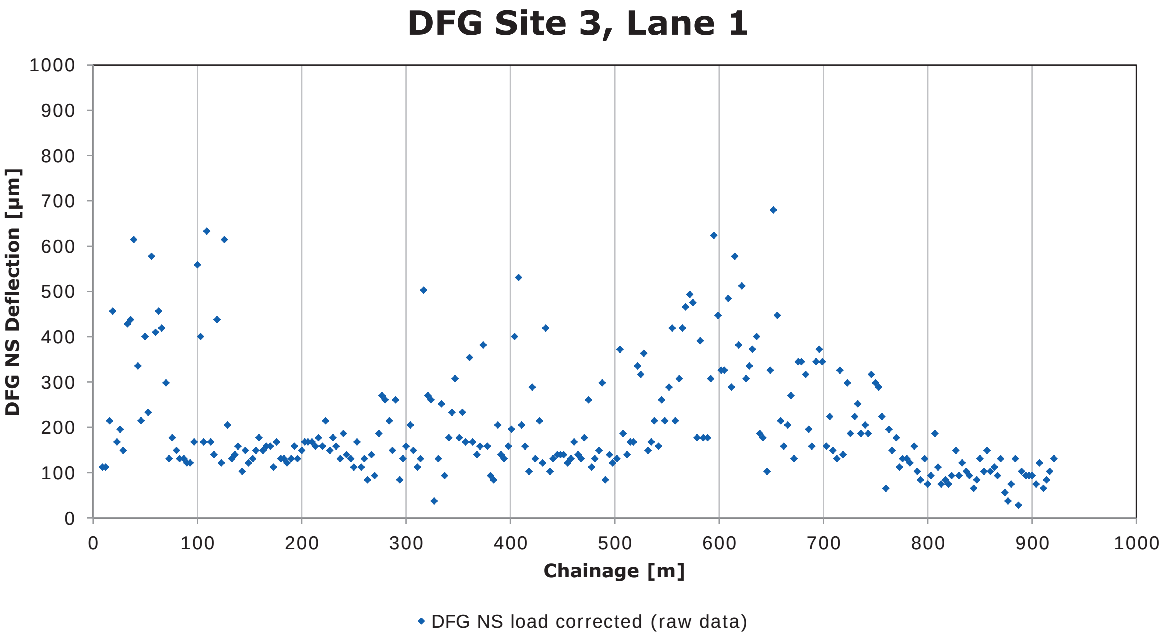
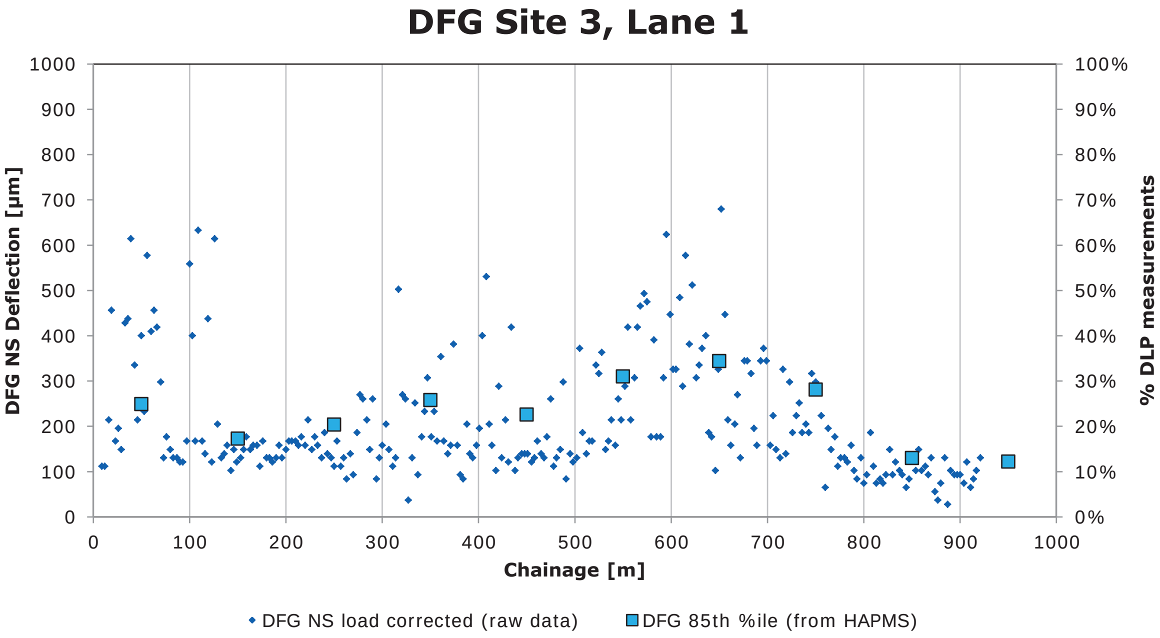
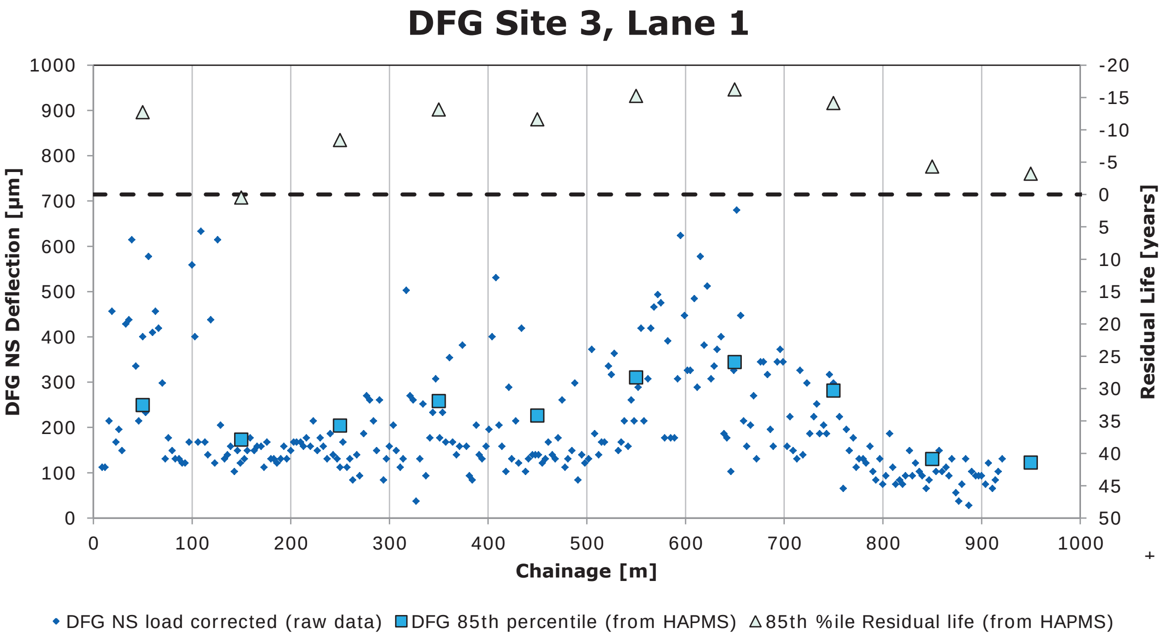
Examples from site surveys



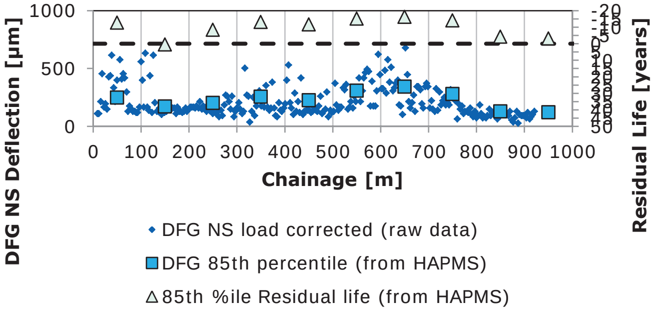


DFG Site 3, Lane 1

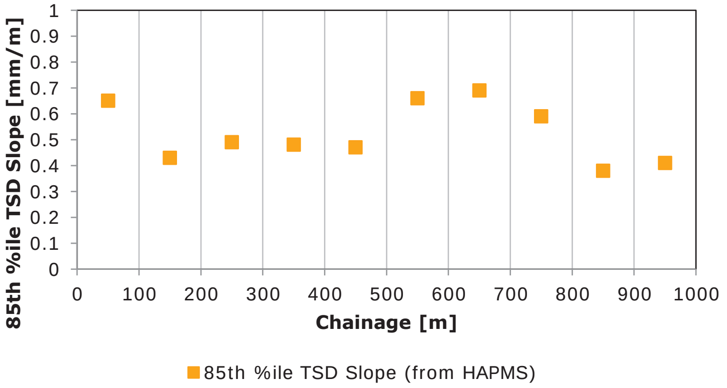


DFG Site 3, Lane 1

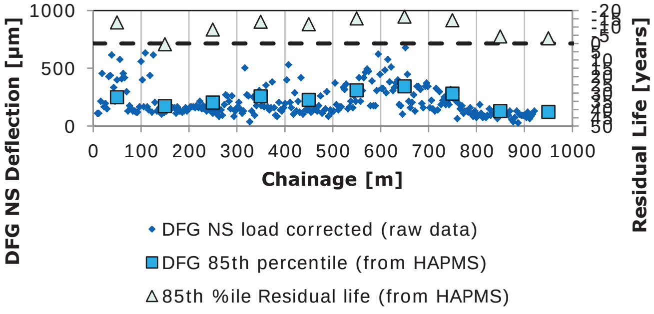
DFG Site 3, Lane 1



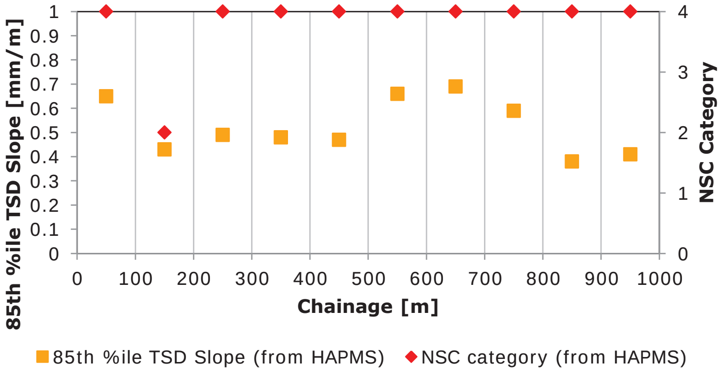
TSD Site 3, Lane 1

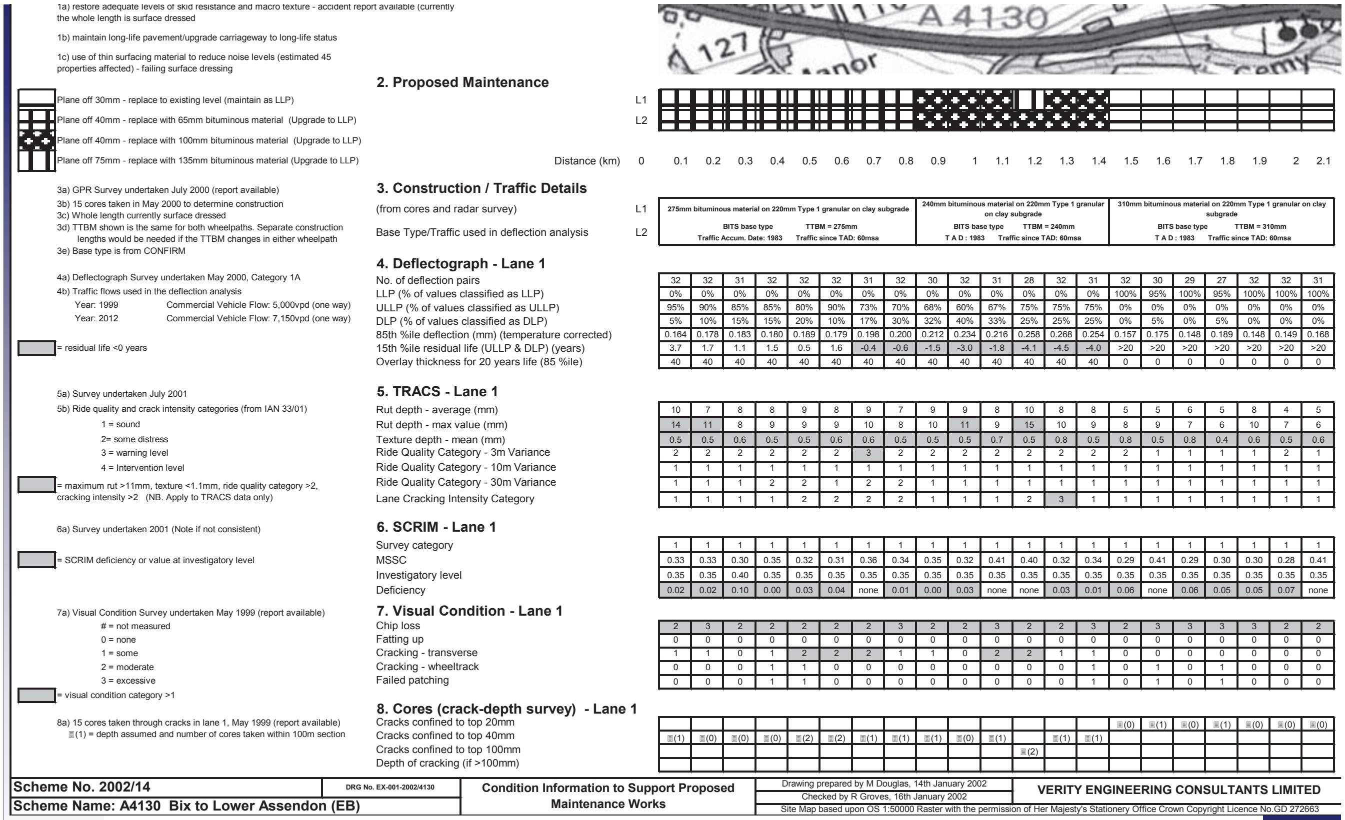


DFG Site 3, Lane 1



TSD Site 3, Lane 1





1a) restore adequate levels of skid resistance and macro texture - accident report available (currently the whole length is surface dressed

1b) maintain long-life pavement/upgrade carriageway to long-life status

1c) use of thin surfacing material to reduce noise levels (estimated 45 properties affected) - failing surface dressing

☐	Plane off 30mm - replace to existing level (maintain as LLP)
▦	Plane off 40mm - replace with 65mm bituminous material (Upgrade to LLP)
▩	Plane off 40mm - replace with 100mm bituminous material (Upgrade to LLP)
▥	Plane off 75mm - replace with 135mm bituminous material (Upgrade to LLP)

2. Proposed Maintenance

L1

L2

Distance (km) 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1

3a) GPR Survey undertaken July 2000 (report available)
3b) 15 cores taken in May 2000 to determine construction
3c) Whole length currently surface dressed
3d) TTBM shown is the same for both wheelpaths. Separate construction lengths would be needed if the TTBM changes in either wheelpath
3e) Base type is from CONFIRM

3. Construction / Traffic Details

(from cores and radar survey) L1 Base Type/Traffic used in deflection analysis L2	275mm bituminous material on 220mm Type 1 granular on clay subgrade BITS base type TTBM = 275mm Traffic Accum. Date: 1983 Traffic since TAD: 60msa	240mm bituminous material on 220mm Type 1 granular on clay subgrade BITS base type TTBM = 240mm T A D : 1983 Traffic since TAD: 60msa	310mm bituminous material on 220mm Type 1 granular on clay subgrade BITS base type TTBM = 310mm T A D : 1983 Traffic since TAD: 60msa

4a) Deflectograph Survey undertaken May 2000, Category 1A
4b) Traffic flows used in the deflection analysis
Year: 1999 Commercial Vehicle Flow: 5,000vpd (one way)
Year: 2012 Commercial Vehicle Flow: 7,150vpd (one way)

▒ = residual life <0 years

4. Deflectograph - Lane 1

No. of deflection pairs	32	32	31	32	32	32	31	32	30	32	31	28	32	31	32	30	29	27	32	32	31
LLP (% of values classified as LLP)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	95%	100%	95%	100%	100%	100%
ULLP (% of values classified as ULLP)	95%	90%	85%	85%	80%	90%	73%	70%	68%	60%	67%	75%	75%	75%	0%	0%	0%	0%	0%	0%	0%
DLP (% of values classified as DLP)	5%	10%	15%	15%	20%	10%	17%	30%	32%	40%	33%	25%	25%	25%	0%	5%	0%	5%	0%	0%	0%
85th %ile deflection (mm) (temperature corrected)	0.164	0.178	0.183	0.180	0.189	0.179	0.198	0.200	0.212	0.234	0.216	0.258	0.268	0.254	0.157	0.175	0.148	0.189	0.148	0.149	0.168
15th %ile residual life (ULLP & DLP) (years)	3.7	1.7	1.1	1.5	0.5	1.6	-0.4	-0.6	-1.5	-3.0	-1.8	-4.1	-4.5	-4.0	>20	>20	>20	>20	>20	>20	>20
Overlay thickness for 20 years life (85 %ile)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0	0	0	0	0	0

5a) Survey undertaken July 2001
5b) Ride quality and crack intensity categories (from IAN 33/01)
1 = sound
2= some distress
3 = warning level
4 = Intervention level

▒ = maximum rut >11mm, texture <1.1mm, ride quality category >2, cracking intensity >2 (NB. Apply to TRACS data only)

5. TRACS - Lane 1

Rut depth - average (mm)	10	7	8	8	9	8	9	7	9	9	8	10	8	8	5	5	6	5	8	4	5
Rut depth - max value (mm)	14	11	8	9	9	9	10	8	10	11	9	15	10	9	8	9	7	6	10	7	6
Texture depth - mean (mm)	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.7	0.5	0.8	0.5	0.8	0.5	0.8	0.4	0.6	0.5	0.6
Ride Quality Category - 3m Variance	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Ride Quality Category - 10m Variance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ride Quality Category - 30m Variance	1	1	1	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Lane Cracking Intensity Category	1	1	1	1	2	2	2	2	1	1	1	2	3	1	1	1	1	1	1	1	1

6a) Survey undertaken 2001 (Note if not consistent)

▒ = SCRIM deficiency or value at investigatory level

6. SCRIM - Lane 1

Survey category	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MSSC	0.33	0.33	0.30	0.35	0.32	0.31	0.36	0.34	0.35	0.32	0.41	0.40	0.32	0.34	0.29	0.41	0.29	0.30	0.30	0.28	0.41
Investigatory level	0.35	0.35	0.40	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Deficiency	0.02	0.02	0.10	0.00	0.03	0.04	none	0.01	0.00	0.03	none	none	0.03	0.01	0.06	none	0.06	0.05	0.05	0.07	none

7a) Visual Condition Survey undertaken May 1999 (report available)
# = not measured
0 = none
1 = some
2 = moderate
3 = excessive

▒ = visual condition category >1

7. Visual Condition - Lane 1

Chip loss	2	3	2	2	2	2	2	3	2	2	3	2	2	3	2	3	3	3	3	2	2
Fatting up	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cracking - transverse	1	1	0	1	2	2	2	1	1	0	2	2	1	1	0	0	0	0	0	0	0
Cracking - wheeltrack	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0
Failed patching	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0

8a) 15 cores taken through cracks in lane 1, May 1999 (report available)
▤(1) = depth assumed and number of cores taken within 100m section

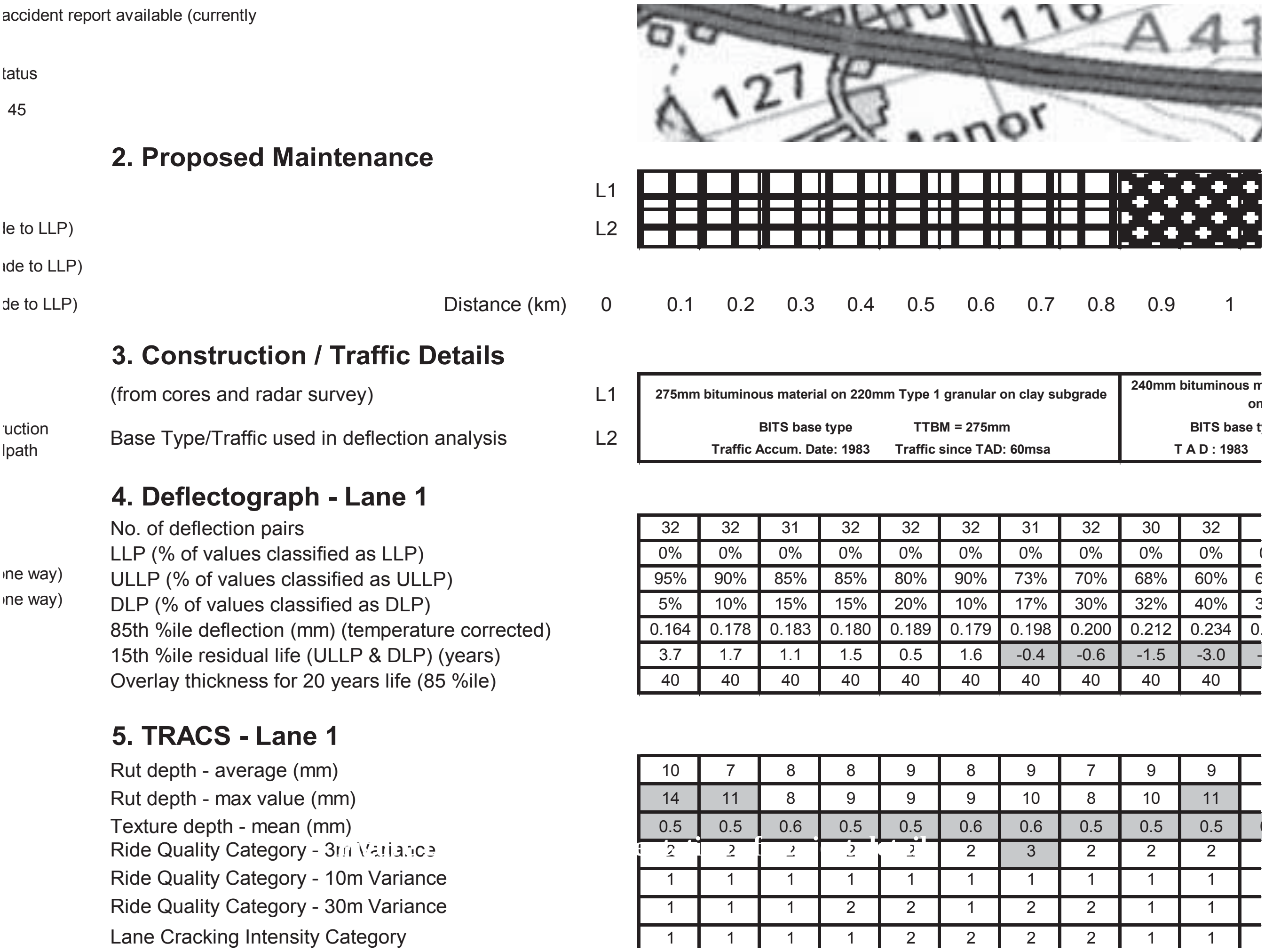
8. Cores (crack-depth survey) - Lane 1

Cracks confined to top 20mm															▤(0)	▤(1)	▤(0)	▤(1)	▤(0)	▤(0)	▤(0)
Cracks confined to top 40mm	▤(1)	▤(0)	▤(0)	▤(0)	▤(2)	▤(2)	▤(1)	▤(1)	▤(1)	▤(0)	▤(1)		▤(1)	▤(1)							
Cracks confined to top 100mm												▤(2)									
Depth of cracking (if >100mm)																					

Scheme No. 2002/14	DRG No. EX-001-2002/4130	Condition Information to Support Proposed Maintenance Works	Drawing prepared by M Douglas, 14th January 2002 Checked by R Groves, 16th January 2002
Scheme Name: A4130 Bix to Lower Assendon (EB)			VERITY ENGINEERING CONSULTANTS LIMITED

Site Map based upon OS 1:50000 Raster with the permission of Her Majesty's Stationery Office Crown Copyright Licence No.GD 272663

Figure D1. Example presentation of project details



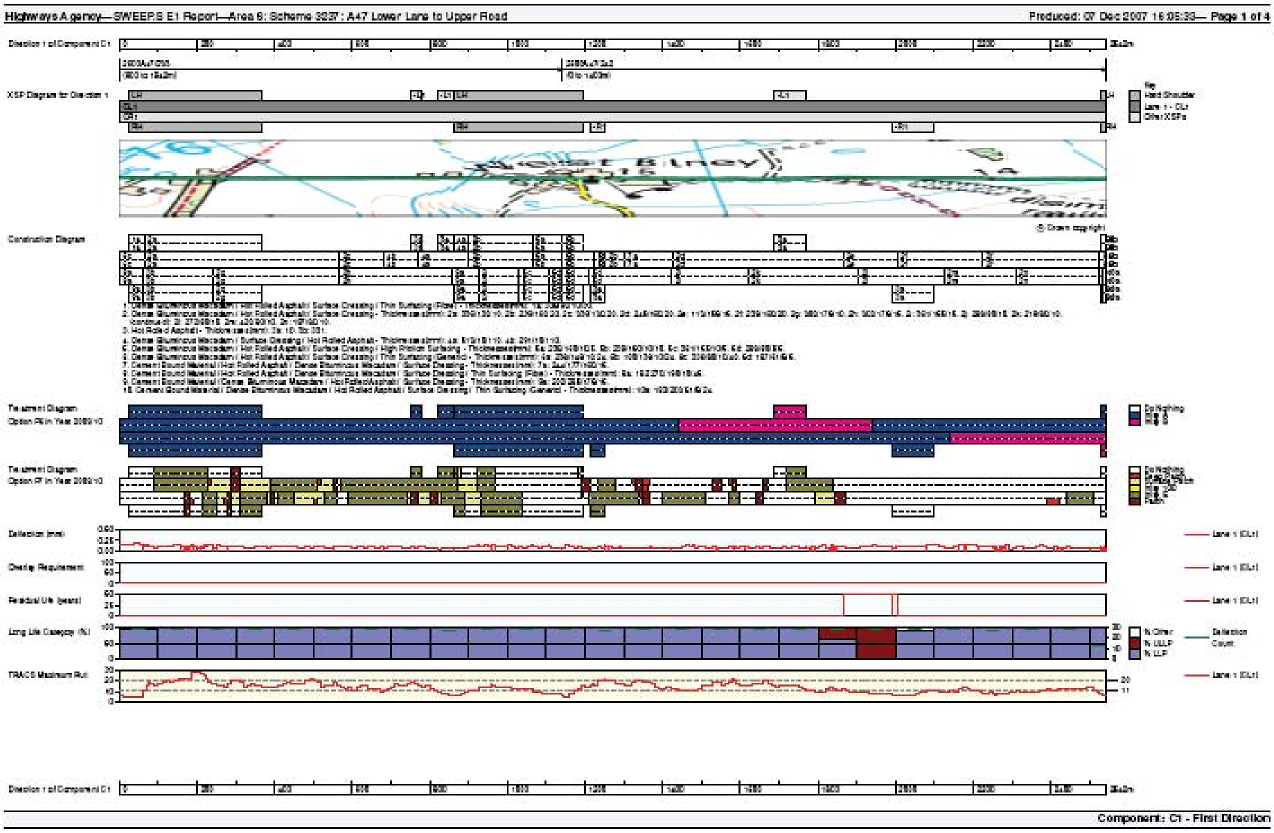
accident report available (currently
tatus
45

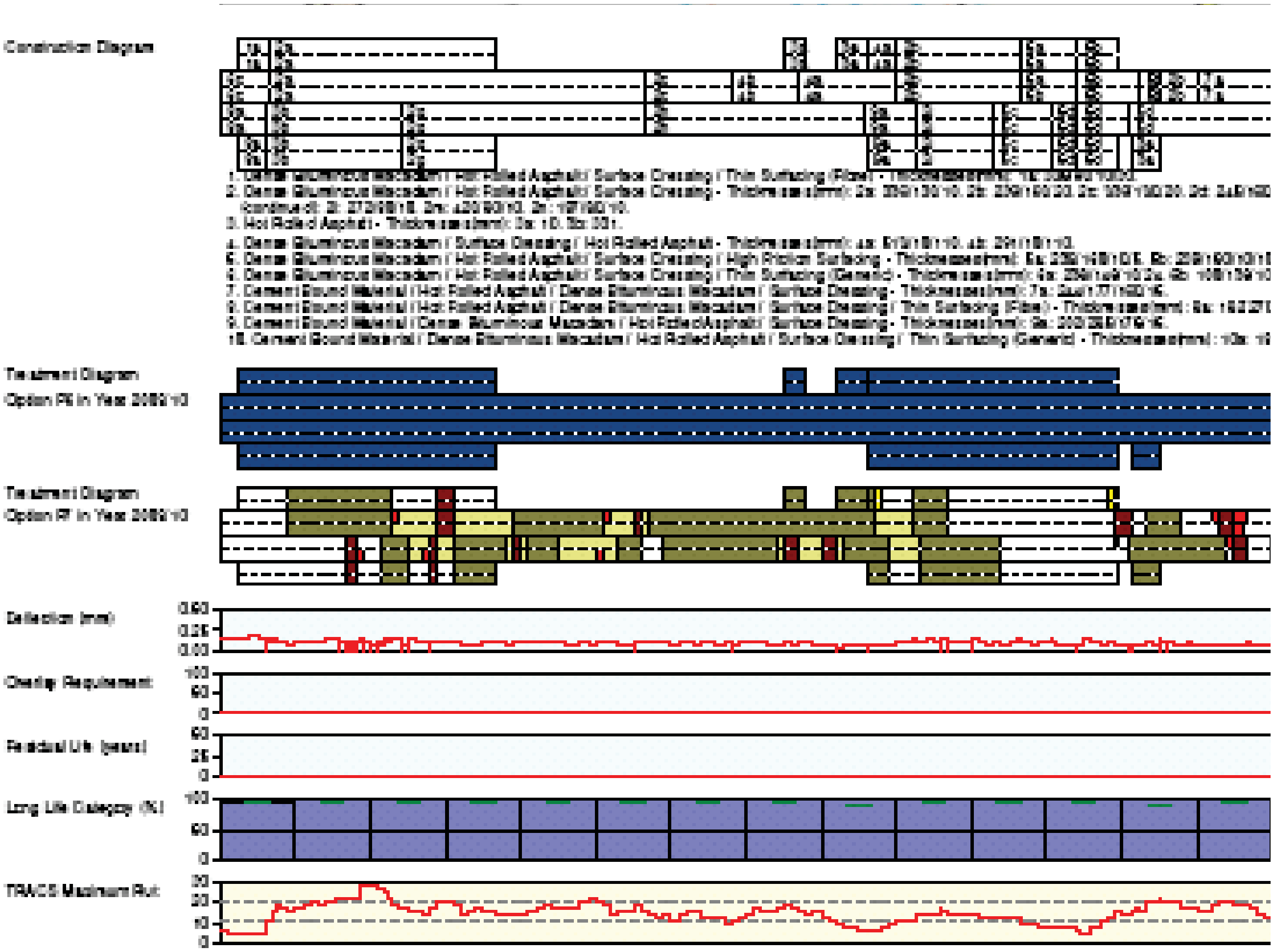
2. Proposed Maintenance
L1
L2
le to LLP)
ıde to LLP)
de to LLP)
Distance (km) 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

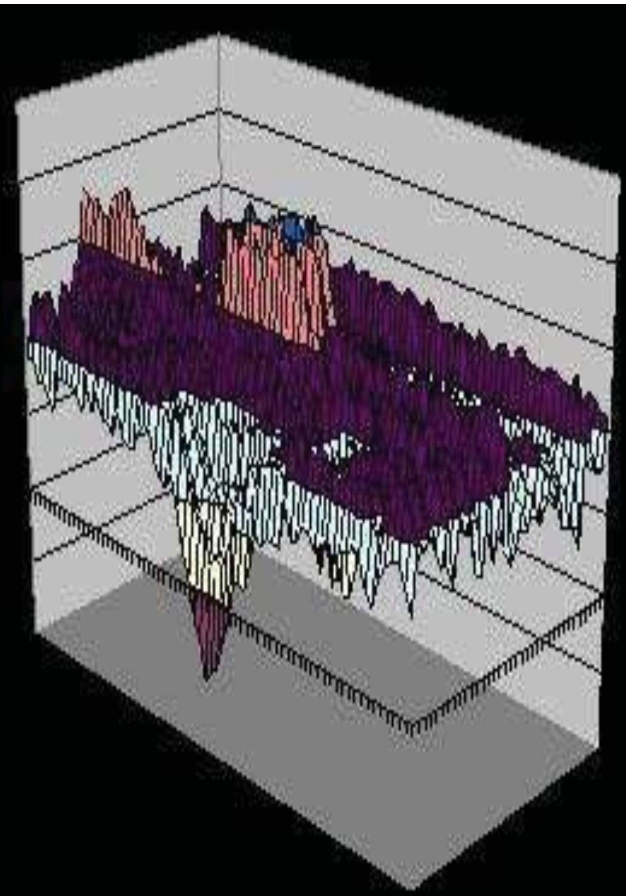
3. Construction / Traffic Details
(from cores and radar survey) L1
Base Type/Traffic used in deflection analysis L2
275mm bituminous material on 220mm Type 1 granular on clay subgrade
BITS base type TTBM = 275mm
Traffic Accum. Date: 1983 Traffic since TAD: 60msa

4. Deflectograph - Lane 1
No. of deflection pairs 32 32 31 32 32 32 31 32 30 32
LLP (% of values classified as LLP) 0% 0% 0% 0% 0% 0% 0% 0% 0% 0%
ULLP (% of values classified as ULLP) 95% 90% 85% 85% 80% 90% 73% 70% 68% 60%
DLP (% of values classified as DLP) 5% 10% 15% 15% 20% 10% 17% 30% 32% 40%
85th %ile deflection (mm) (temperature corrected) 0.164 0.178 0.183 0.180 0.189 0.179 0.198 0.200 0.212 0.234
15th %ile residual life (ULLP & DLP) (years) 3.7 1.7 1.1 1.5 0.5 1.6 -0.4 -0.6 -1.5 -3.0
Overlay thickness for 20 years life (85 %ile) 40 40 40 40 40 40 40 40 40 40

5. TRACS - Lane 1
Rut depth - average (mm) 10 7 8 8 9 8 9 7 9 9
Rut depth - max value (mm) 14 11 8 9 9 9 10 8 10 11
Texture depth - mean (mm) 0.5 0.5 0.6 0.5 0.5 0.6 0.6 0.5 0.5 0.5
Ride Quality Category - 3m Variance 2 2 2 2 2 2 3 2 2 2
Ride Quality Category - 10m Variance 1 1 1 1 1 1 1 1 1 1
Ride Quality Category - 30m Variance 1 1 1 2 2 1 2 2 1 1
Lane Cracking Intensity Category 1 1 1 1 2 2 2 2 1 1


Highways Agency—SWEEPS E1 Report—Area 6: Scheme 3237: A47 Lower Lane to Upper Road
Produced: 07 Dec 2007 16:05:33— Page 1 of 4
Direction 1 of Component C1
XSP Diagram for Direction 1
Key
Hard Shoulder
Lane 1 - CL1
Other XSPs
© Crown copyright
Construction Diagram
Treatment Diagram Option P6 in Year 2009/10
Do Nothing
Treatment Diagram Option P7 in Year 2009/10
Do Nothing
Deflection (mm)
Overlay Requirement
Residual Life (years)
Long Life Category (%)
% Other
% ULLP
% LLP
Deflection Count
TRACS Maximum Rut
Lane 1 (CL1)
Component: C1 - First Direction


Construction Diagram
1. Dense Bituminous Macadam / Hot Rolled Asphalt / Surface Dressing / Thin Surfacing (Fibre) - Thicknesses(mm):
2. Dense Bituminous Macadam / Hot Rolled Asphalt / Surface Dressing - Thicknesses(mm):
3. Hot Rolled Asphalt - Thicknesses(mm):
4. Dense Bituminous Macadam / Surface Dressing / Hot Rolled Asphalt - Thicknesses(mm):
5. Dense Bituminous Macadam / Hot Rolled Asphalt / Surface Dressing / High Friction Surfacing - Thicknesses(mm):
6. Dense Bituminous Macadam / Hot Rolled Asphalt / Surface Dressing / Thin Surfacing (Generic) - Thicknesses(mm):
7. Cement Bound Material / Hot Rolled Asphalt / Dense Bituminous Macadam / Surface Dressing - Thicknesses(mm):
8. Cement Bound Material / Hot Rolled Asphalt / Dense Bituminous Macadam / Surface Dressing / Thin Surfacing (Fibre) - Thicknesses(mm):
9. Cement Bound Material / Dense Bituminous Macadam / Hot Rolled Asphalt / Surface Dressing - Thicknesses(mm):
10. Cement Bound Material / Dense Bituminous Macadam / Hot Rolled Asphalt / Surface Dressing / Thin Surfacing (Generic) - Thicknesses(mm):
Treatment Diagram Option P6 in Year 2009/10
Treatment Diagram Option P7 in Year 2009/10
Deflection (mm)
Overlay Requirement
Residual Life (years)
Long Life Category (%)
TRACS Maximum Rut
0.50
0.25
0.00
100
50
0
50
25
0
100
50
0
30
20
10
0



Thank your for listening!

bferne@trl.co.uk