Session 2B - Infrastructure 2

# Paper Title:

# Load Equivalency Factors (LEFs) for Abnormal Vehicles (AVs) and Mobile Cranes in South Africa based on the Mechanistic-Empirical (M-E) Design Methodology

*M De Beer,*
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*M Kemp*

*CSIR Built Environment (CSIR BE), Pretoria*

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# Abnormal Heavy Vehicles - Road Users..:

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# Basic Idea for AV Permits…:

**ROAD DAMAGE FACTOR = LOAD EQUIVELANCY FACTOR (LEF);**

**Cost of Permit = LEF x 32 c /80kN-lane km**

**(Current ZAR = 0.32 c)**

# Project Layout (In Paper) - 1:

- INTRODUCTION AND SCOPE
- EQUIVALENT PAVEMENT RESPONSE (EPR)- EQUIVALENT PAVEMENT DAMAGE (EPD)
- PRINCIPLES OF THE NEW “EPR-EPD” METHOD
  USE OF ESWL (or ESWM) ON CALCULATION OF THE MASS FEE
- PAVEMENT TYPES AND CONDITIONS EVALUATED IN THIS STUDY
- MOBILE CRANES AND EXAMPLES
- ABNORMAL VEHICLES (AVs) AND EXAMPLES
- SOFTWARE FOR CALCULATION OF ROAD DAMAGE
- TYRE INFLATION PRESSURES (i.e. CONTACT STRESS)
- PROPOSED FORMULATIONS FOR ESTIMATING ROAD DAMAGE
- Legal Damage (LDv):
- Total Damage (TDv) (= Load Equivalency Factor (LEFv) of Vehicle):
- Total Additional Damage (TADv):
- MASS FEE AND PERMIT FEE FOR ROAD DAMAGE ONLY

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# Project Layout (In Paper) - 2 :

- LEF RESULTS FOR THE ABNORMAL VEHICLES AND MOBILE CRANES
    - Mobile Cranes - LEFs
    - Mobile Cranes - Current damage LEFs - WET pavement conditions
    - Abnormal Vehicles (AVs) - LEFs
    - AVs - Current damage LEFs - WET pavement conditions

EFFECT OF TYRE INFLATION PRESSURES (TiPs) ON LEFs

Mobile Cranes – Average damage LEFs over a range of TiPs

- Mobile Cranes - Average damage LEFs - DRY pavement conditions
- Mobile Cranes - Average damage LEFs - WET pavement conditions
- AVs – Average damage LEFs over a range of TiPs
- AVs - Average damage LEFs - DRY pavement conditions
- AVs - Average damage LEFs - WET pavement conditions
- SUMMARY
- CONCLUSIONS
- RECOMMENDATIONS

# Project Objectives:

- Quantification of the Road Damage using M-E Load Equivalency Factors;
- Effect of each vehicle on Different Pavement Structures and Moisture Conditions
- Basis - Mechanistic – Empirical (M-E) Design
- To give practical Conclusions and Recommendations to industry/Road Authorities.

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# Basic Idea for AV Permits…:

**ROAD DAMAGE FACTOR = LOAD EQUIVELANCY FACTOR (LEF);**

**Cost of Permit = LEF x 32 c /80kN-lane km**

**(Current ZAR = 0.32 c)**

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# Analysis Matrix:

- **11** Cranes X **9** Pavement Structures x **2** Conditions (wet/dry) x **8** Abnormal Vehicles (AVs) x **8** Tyre Inflation Pressures = **12 672** computer runs

(…more than once…!!)

# EQUIVALENT SINGLE WHEEL/MASS- ESWL/ESWM

- 1970'S: Van Vuuren – PhD:
- ESWL/ESWM

- Influence of nearest tyre……on ESWL/M

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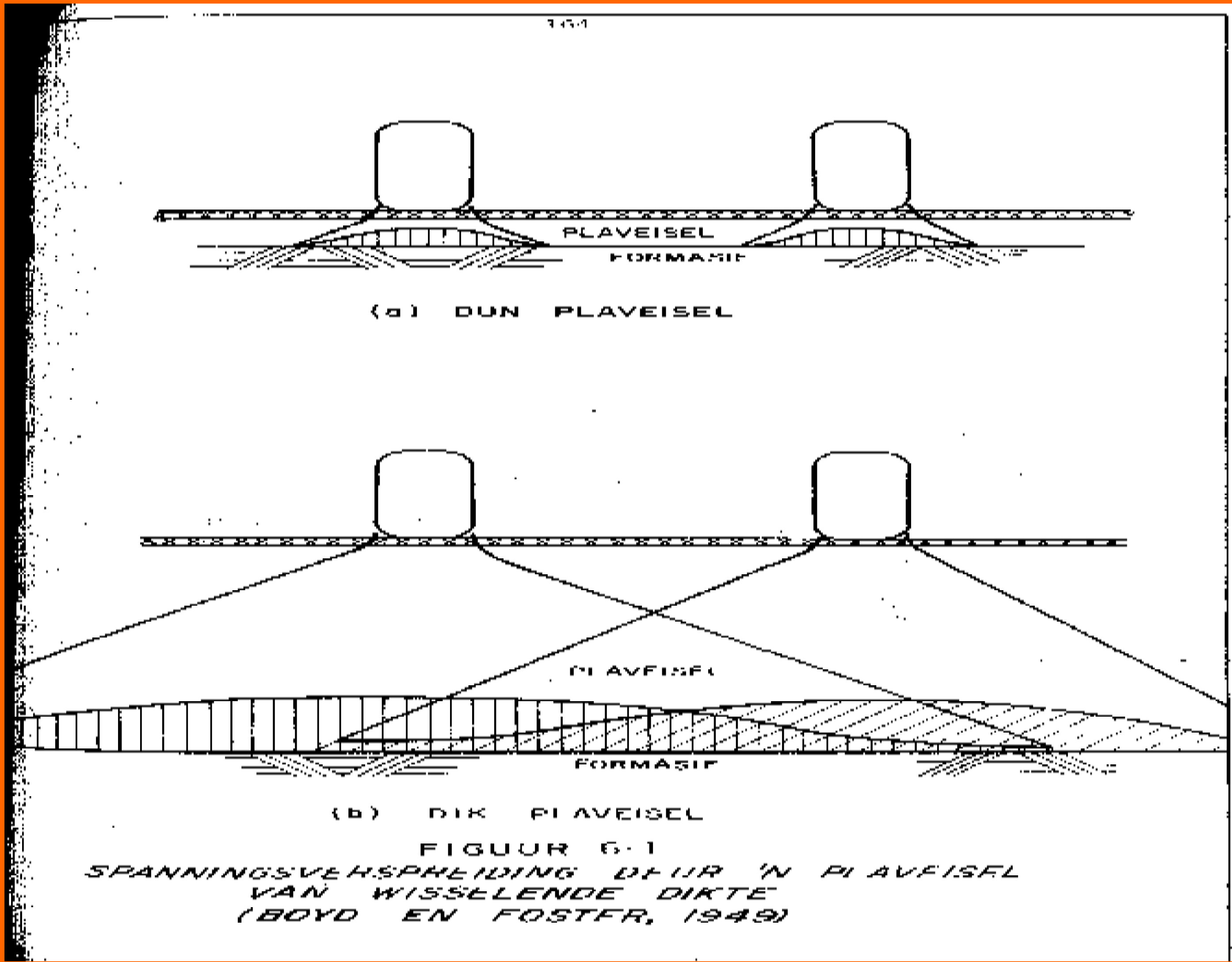
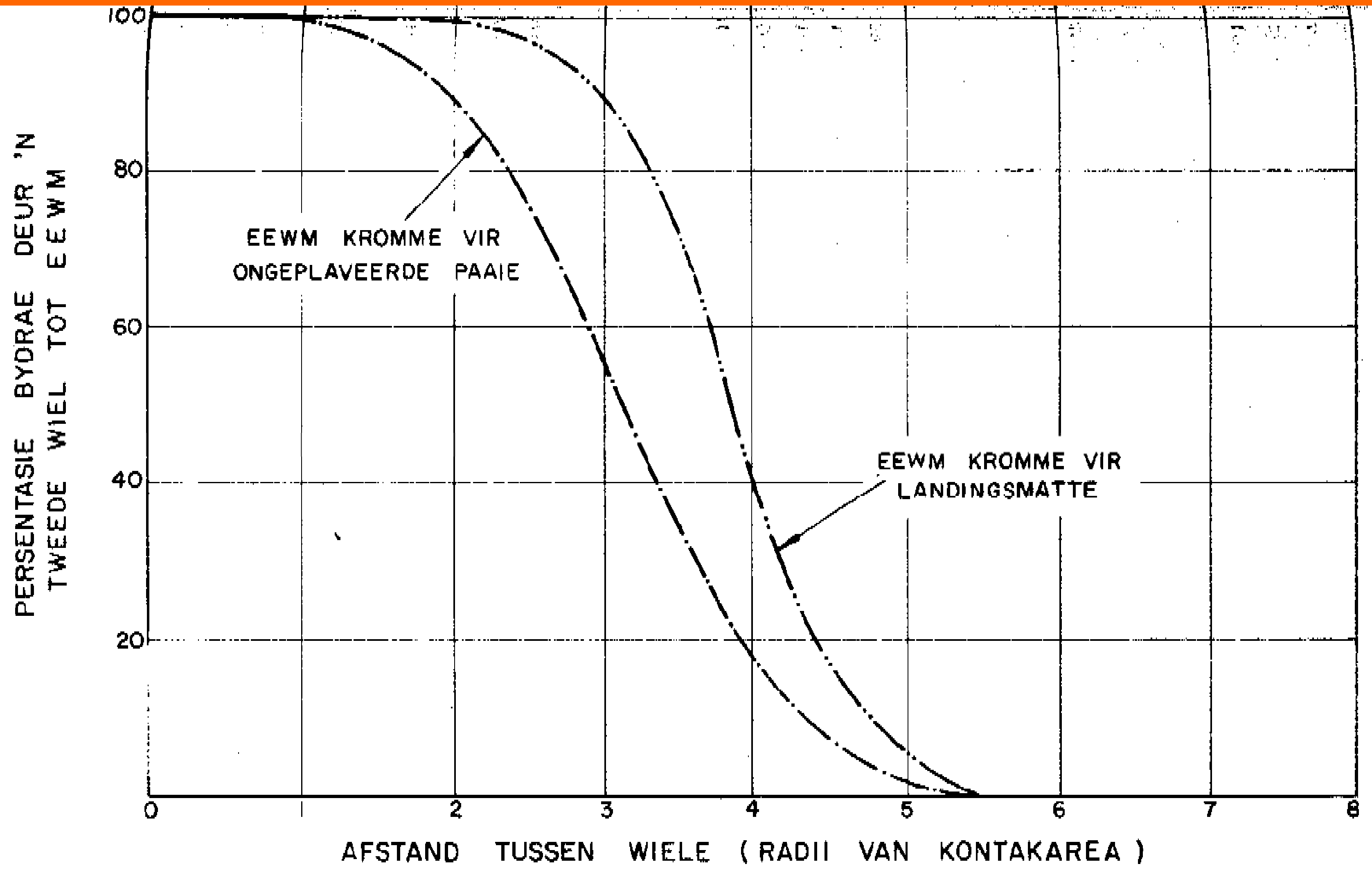
# EQUIVALENT SINGLE WHEEL/MASS- ESWL/ESWM

- 1970'S: Van Vuuren – PhD:
- ESWL/ESWM




FIGUUR 6-1
SPANNINGSVERSPREIDING DEUR 'N PLAVEISEL VAN WISSELENDE DIKTE (BOYD EN FOSTER, 1949)

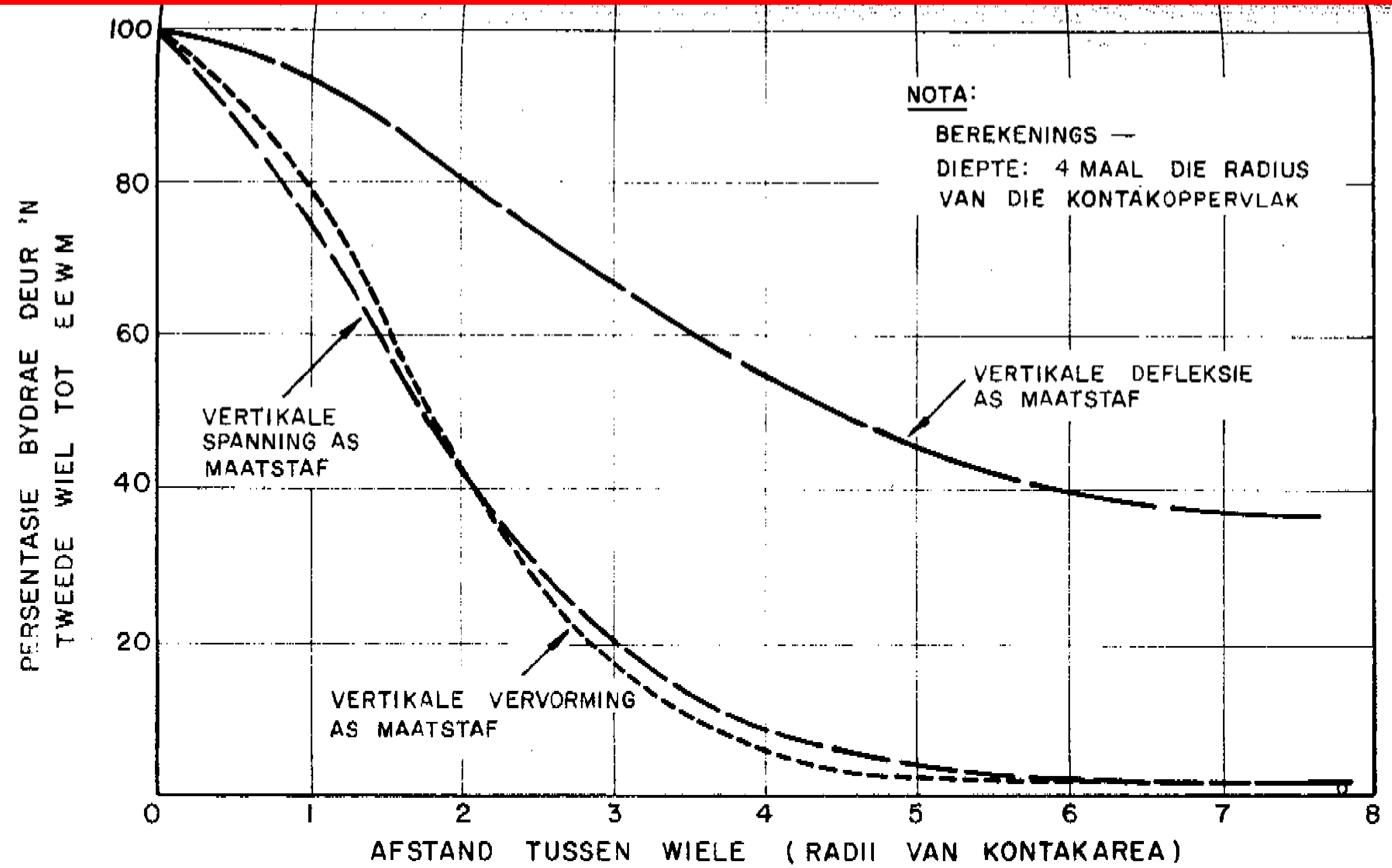
# EQUIVALENT SINGLE WHEEL/MASS- ESWL/ESWM




FIGUUR 6 – 8

*PERSENTASIE BYDRAE TOT EEWM VAN 'N TWEEDE WIEL*
*( U.S. CORPS OF ENGINEERS GRONDFLOTASIESTUDIE )*

# EQUIVALENT SINGLE WHEEL/MASS- ESWL/ESWM




FIGUUR 6-7

*PERSENTASIE BYDRAE TOT EEWM VAN 'N TWEEDE WIEL BEREKEN mbv VERSKILLENDE MAATSTAWWE*

# EQUIVALENT SINGLE WHEEL/MASS- ESWL/ESWM

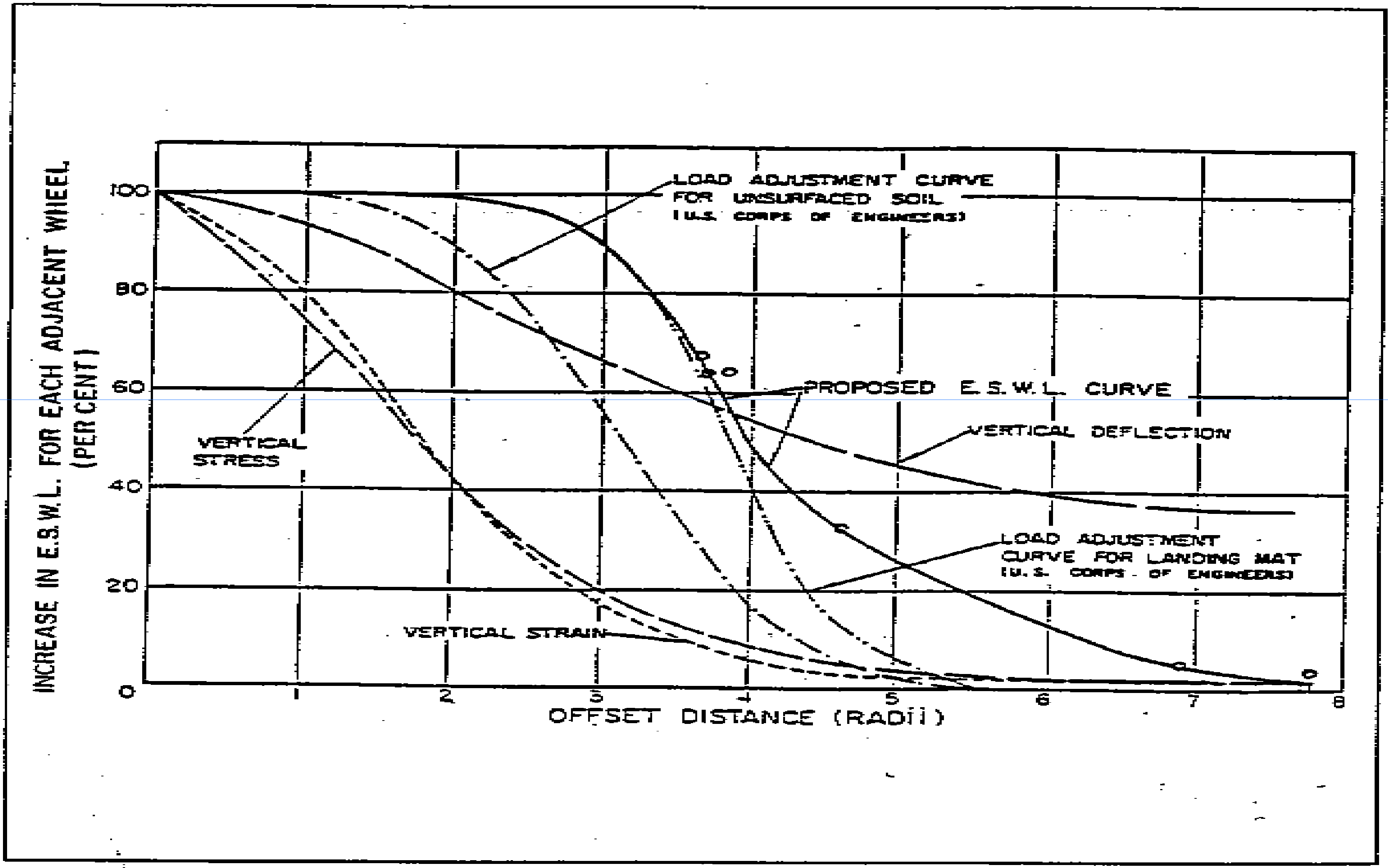



FIGURE 1 : ESWL VERSUS OFFSET OF SECOND WHEEL (from ref 2)

# EQUIVALENT SINGLE WHEEL/MASS- ESWL/ESWM

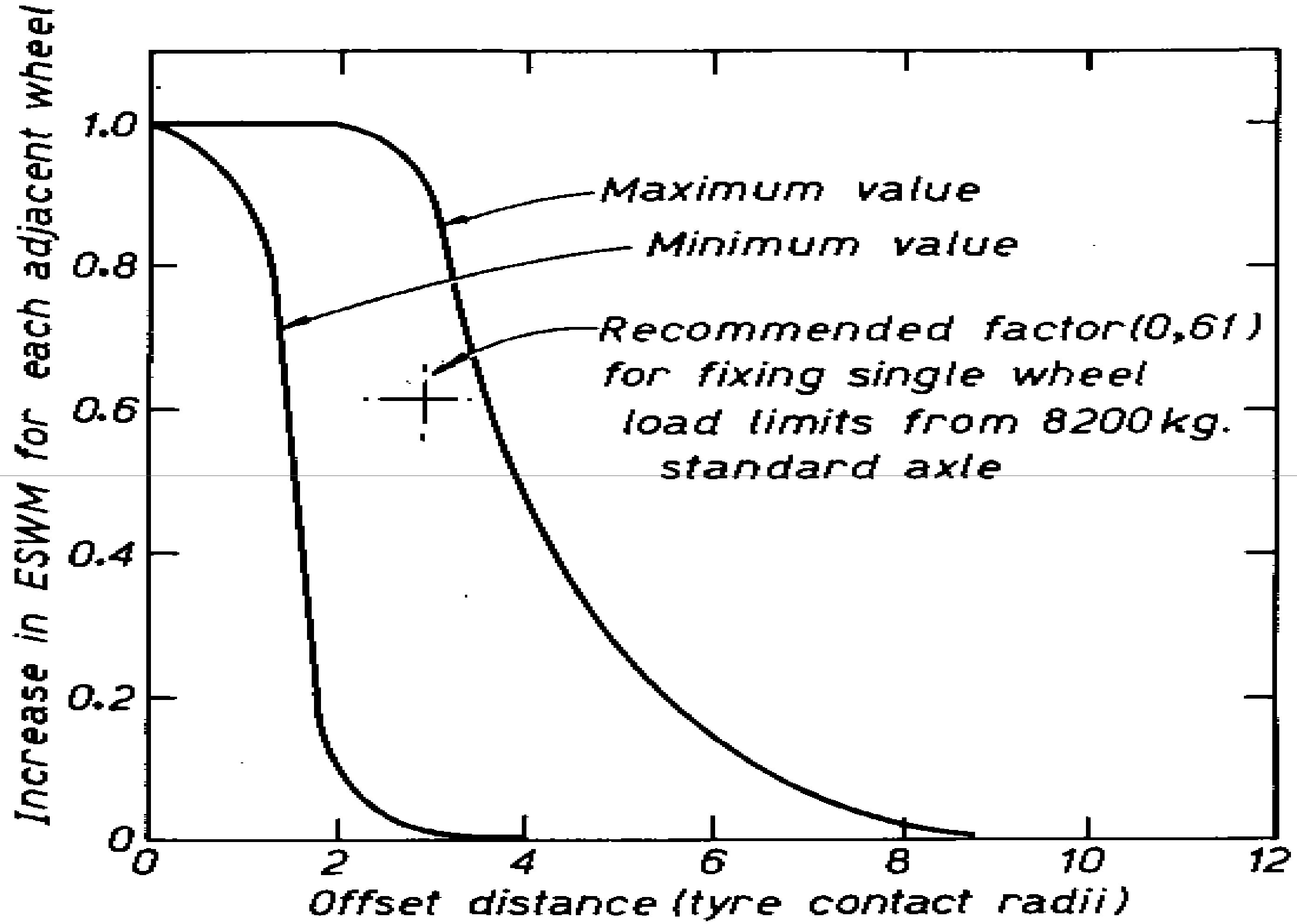



Fig. 16 MAXIMUM AND MINIMUM ENVELOPES OF ESWM OFFSET INFLUENCE LINE.

# Road Infrastructure Protection….:

Thin Asphalt Surfacings (30 mm to 50 mm) on crushed rock: Economical in dry regions.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# Heavy Vehicles - Road Users:



 

# Mobile Cranes…………




# Mobile Cranes…………



# Mobile Cranes…………

12-Axle…

# Mobile Cranes…………


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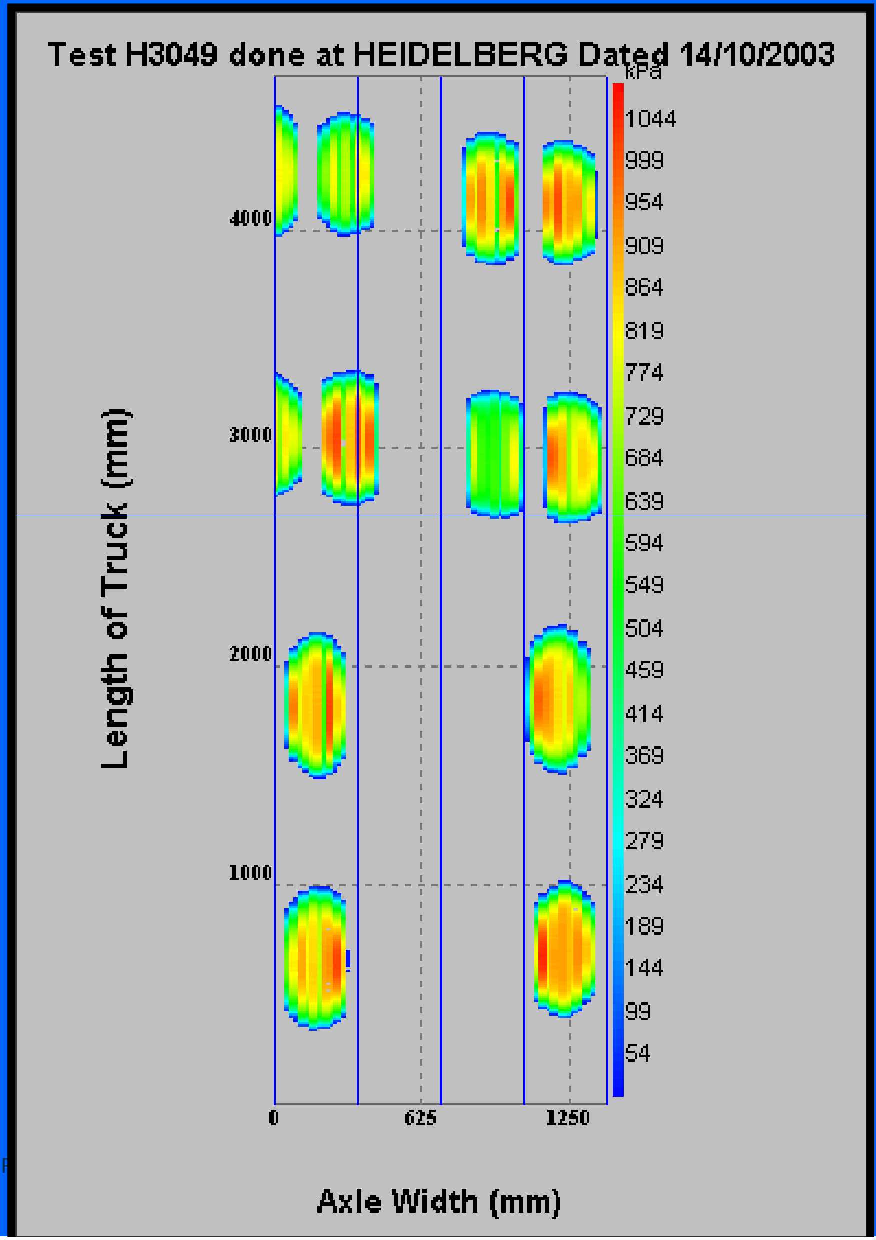
# Mobile Cranes – Tyre/Axle Footprint..

*Tyre Footprints/ "Fingerprints"….*



# Heavy Vehicles - Road Users:

# Heavy Vehicles - Road Users:

# Abnormal Heavy Vehicles (AVs) -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# Abnormal Heavy Vehicles (AVs) -

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# Abnormal Heavy Vehicles (AVs) -




 

# Abnormal Heavy Vehicles (AVs) -

# Abnormal Heavy Vehicles (AVs) - Gautrain

# Abnormal Heavy Vehicles (AVs) - Gautrain


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# Abnormal Heavy Vehicles (AVs) -

# Abnormal Heavy Vehicles (AVs) -




 

# Abnormal Heavy Vehicles (AVs) -

# Abnormal Heavy Vehicles (AVs) -




 

# Heavy Vehicles - Road Users:

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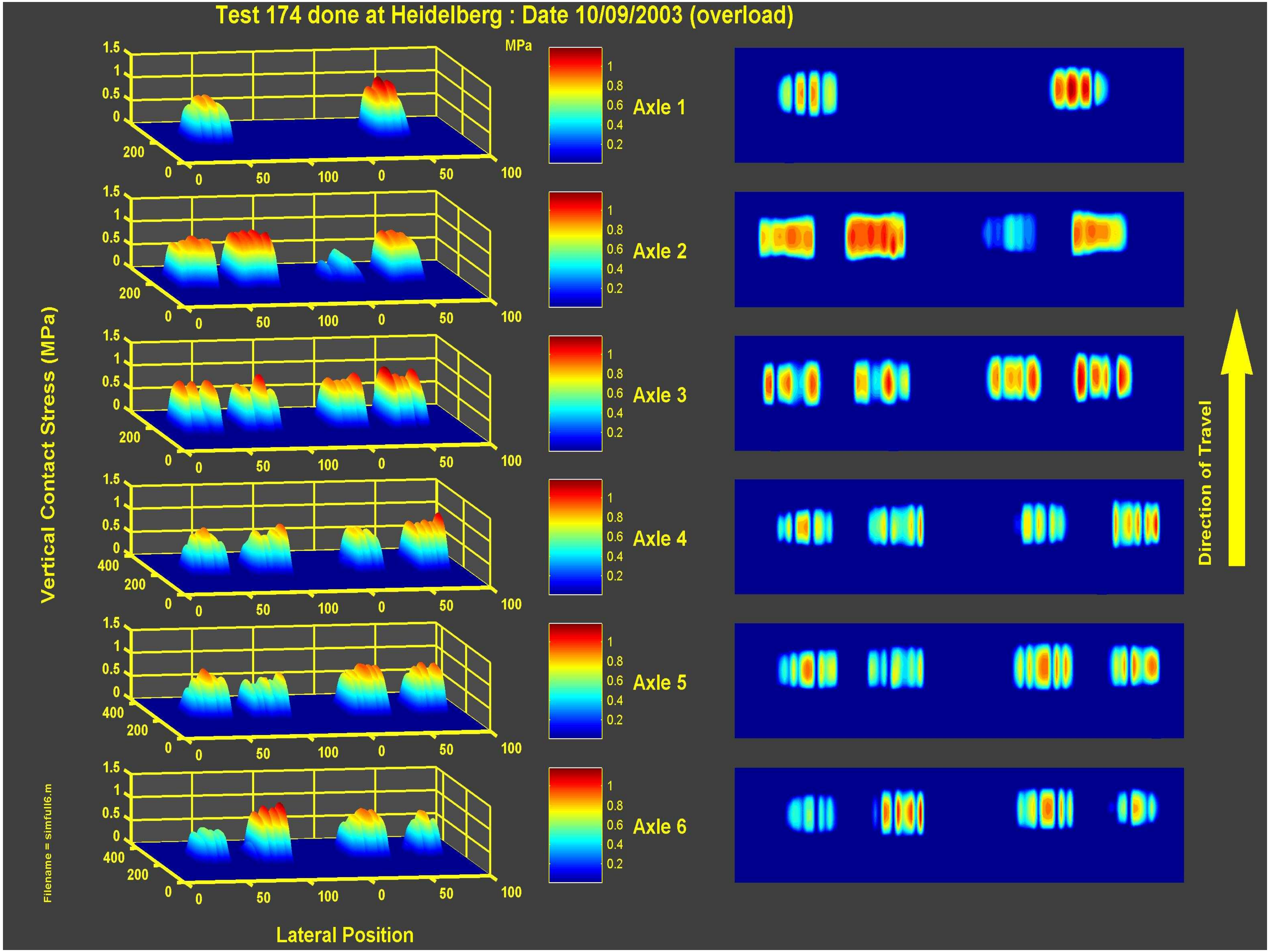
Test 174 done at Heidelberg : Date 10/09/2003 (overload)
MPa
Axle 1
Axle 2
Axle 3
Axle 4
Axle 5
Axle 6
Vertical Contact Stress (MPa)
Lateral Position
Direction of Travel
Filename = simfull6.m


POTHOLES

# Road Damage..

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# Road Damage. cracking…

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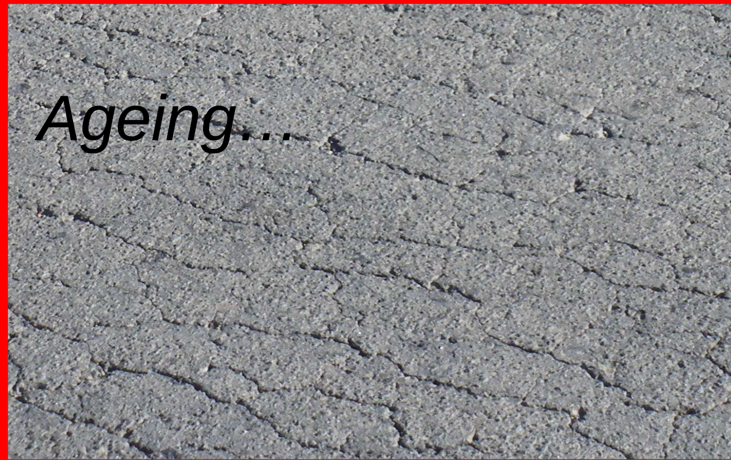
# Road Damage. cracking…

# Road Damage. cracking & Pumping.....

# Road Damage. cracking & Potholes…



*Ageing…*

# Road Damage. Potholes…Wet…

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# Extreme Road Damage. Potholes…



 

# Extreme Road Damage. Shear Failure - Potholes...

# Plastic flow/shear - Road Failures:


# Upgrading of Gravel Roads….

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# ..to Paved all-weather roads…

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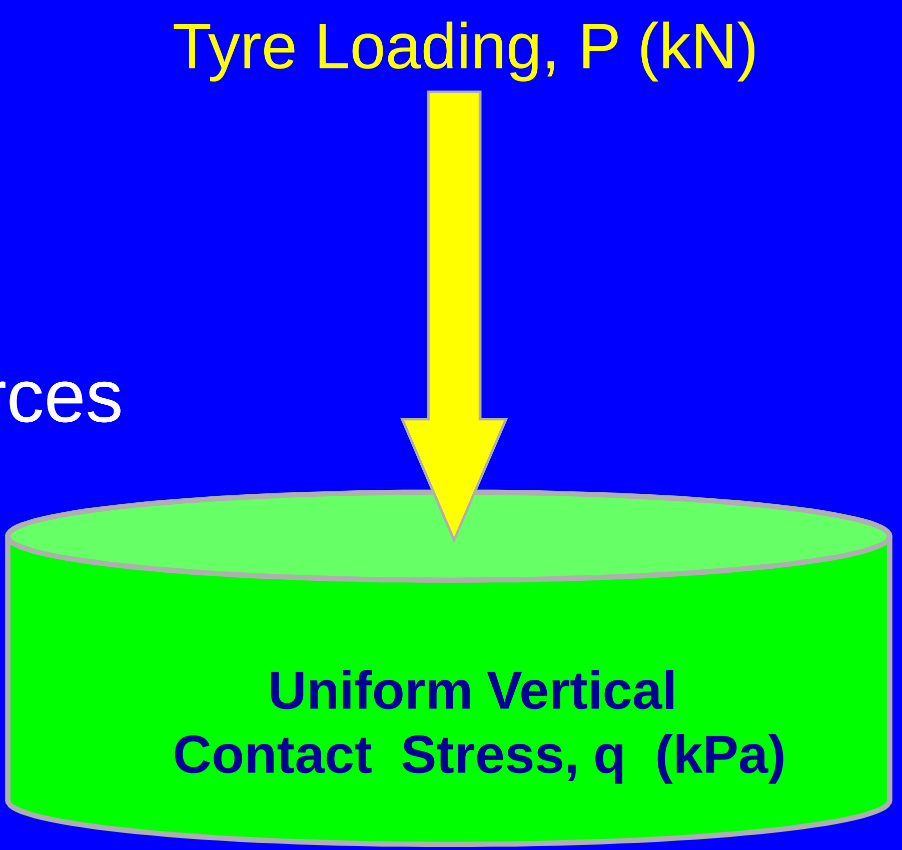
Road Damage Analysis…..

# Assumption of Tyre Loading – Pavement Design Modeling:

- Circular;
- Variable Vertical load;
- Variable pressure,

but UNIFORM &

No Shear (tangential) Forces included in this study...



## EQUIVALENT PAVEMENT RESPONSE (EPR)- EQUIVALENT PAVEMENT DAMAGE (EPD):

- PRINCIPLE OF THE NEW "EPR-EPD" METHOD:

*- Equal Stresses, Strains - Structural Performance (via HVS & Practical Experience i.e. ~Transfer Functions) – Equal "Damage"*

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# HEAVY VEHICLE SIMULATOR (HVS)-[1975-1993]

# HVS Mark IV+ (1994 -….)




RUTTING
SurfaceDisintegration . .
Fatigue Cracking and aging
Delamination..
Longitudinal Flow of Asphalt
SURFACE DISINTEGRATION
Potholes & Patching…
Water&Safety. . .
POTHOLES :
Water & Loads …
Sub-grade Failures… .

# Mechanistic Design

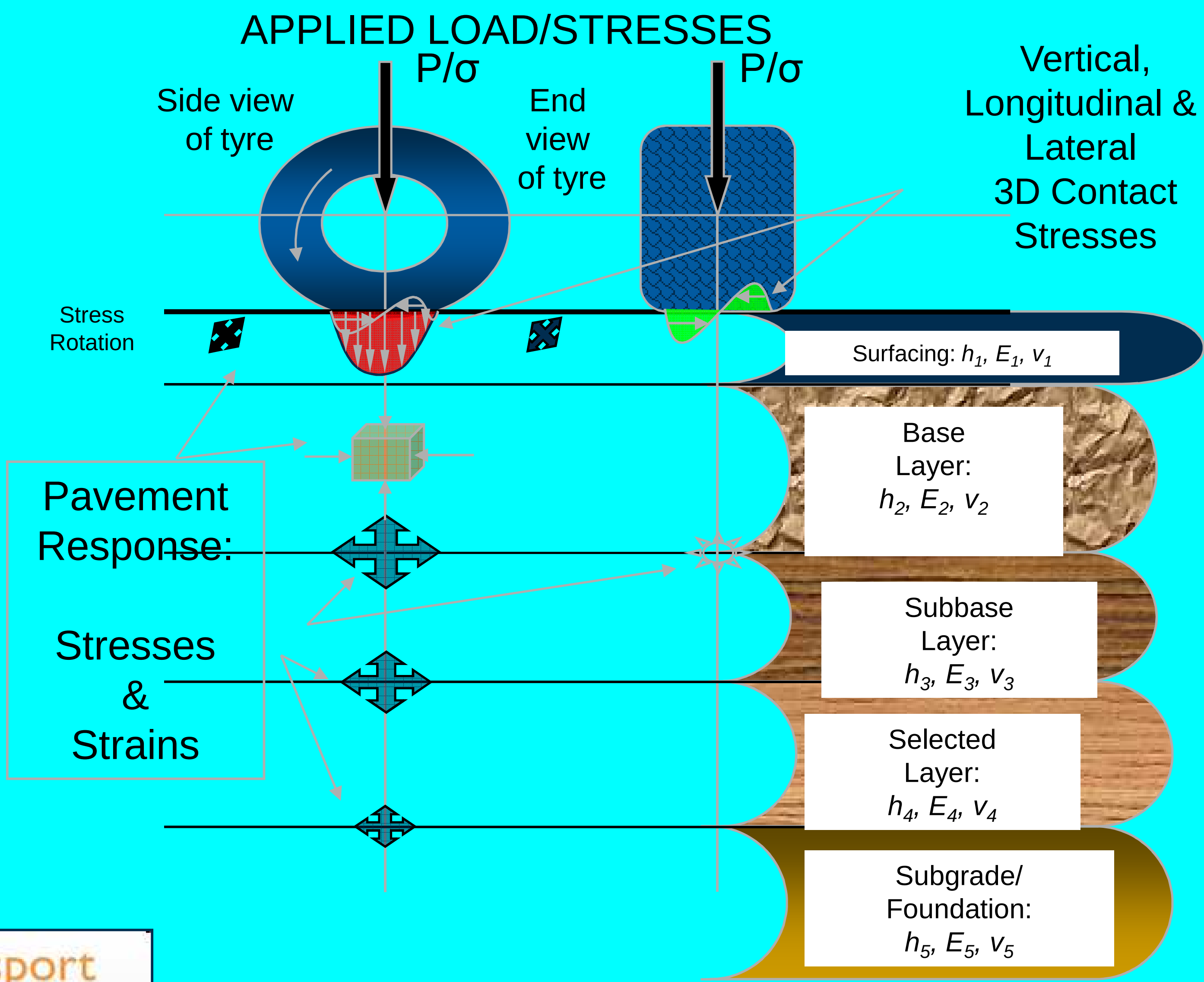
..1996 TRB Paper..

Divisional Publication DP-96/005
*(Reprint of Paper No 961294 - 75th TRB 1996 meeting)*

## Overview of the South African Mechanistic Pavement Design Analysis Method

H L Theyse
M de Beer
F C Rust

# Mechanistic Design

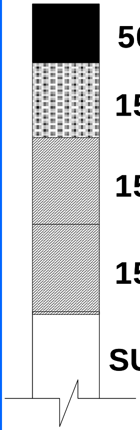




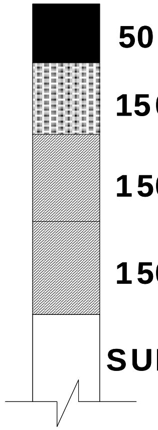
# Pavements Studied…

## Pavement A: ES100



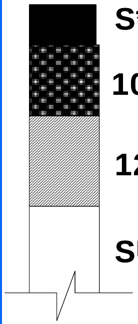
| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II | Phase III |
|---|---|---|---|---|
| 50 AG* | 0.44 | 2000 | 2000 | 1500 |
| 150 G1* | 0.35 | 450 | 450 | 350 |
| 150 C3* | 0.35 | 2000 | 2000 | 500 |
| 150 C3 | 0.35 | 1500 | 550 | 250 |
| SUBGRADE | 0.35 | 180 | 180 | 180 |

## Pavement B: ES100



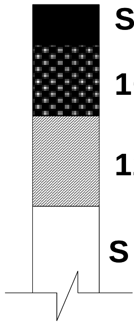
| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II | Phase III |
|---|---|---|---|---|
| 50 AG* | 0.44 | 2000 | 1800 | 1500 |
| 150 G1* | 0.35 | 250 | 250 | 240 |
| 150 C3* | 0.35 | 2000 | 1700 | 160 |
| 150 C3 | 0.35 | 1500 | 120 | 110 |
| SUBGRADE | 0.35 | 90 | 90 | 90 |

## Pavement C: ES0.1



| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II |
|---|---|---|---|
| S* | 0.44 | 1000 | 1000 |
| 100 G4* | 0.35 | 300 | 225 |
| 125 C4* | 0.35 | 1000 | 200 |
| SUBGRADE | 0.35 | 140 | 140 |
| | - | - | - |

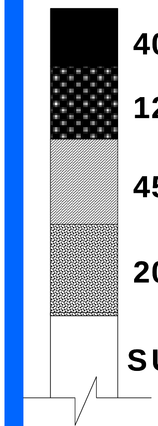
## Pavement D: ES0.1



| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II |
|---|---|---|---|
| S* | 0.44 | 1000 | 1000 |
| 100 G4* | 0.35 | 200 | 180 |
| 125 C4* | 0.35 | 1000 | 120 |
| SUBGRADE | 0.35 | 70 | 70 |
| | - | - | - |

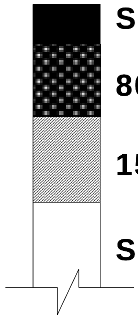
# Pavements Studied...

**Pavement E:
ES30/ES50**



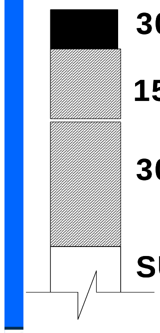
| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II | Phase III |
|---|---|---|---|---|
| 40 AG* | 0.44 | 2500 | 2500 | 1600 |
| 120 BC* | 0.44 | 3500 | 3500 | 1500 |
| 450 C3* | 0.35 | 2200 | 1000 | 300 |
| 200 G7* | 0.35 | 300 | 300 | 200 |
| SUBGRADE | 0.35 | 150 | 150 | 140 |

**Pavement F:
ES1.0**



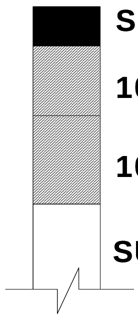
| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II |
|---|---|---|---|
| S* | 0.44 | 2000 | 1600 |
| 80 BC* | 0.44 | 2000 | 1600 |
| 150 C4* | 0.35 | 1000 | 300 |
| SUBGRADE | 0.35 | 140 | 140 |
| | - | - | - |

**Pavement G:
ES10**



| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II | Phase III |
|---|---|---|---|---|
| 30 AG* | 0.44 | 2400 | 2000 | 1600 |
| 150 C3* | 0.35 | 2000 | 1800 | 250 |
| 300 C4* | 0.35 | 1000 | 300 | 100 |
| SUBGRADE | 0.35 | 180 | 140 | 100 |
| | - | - | - | - |

**Pavement H:
ES0.3**



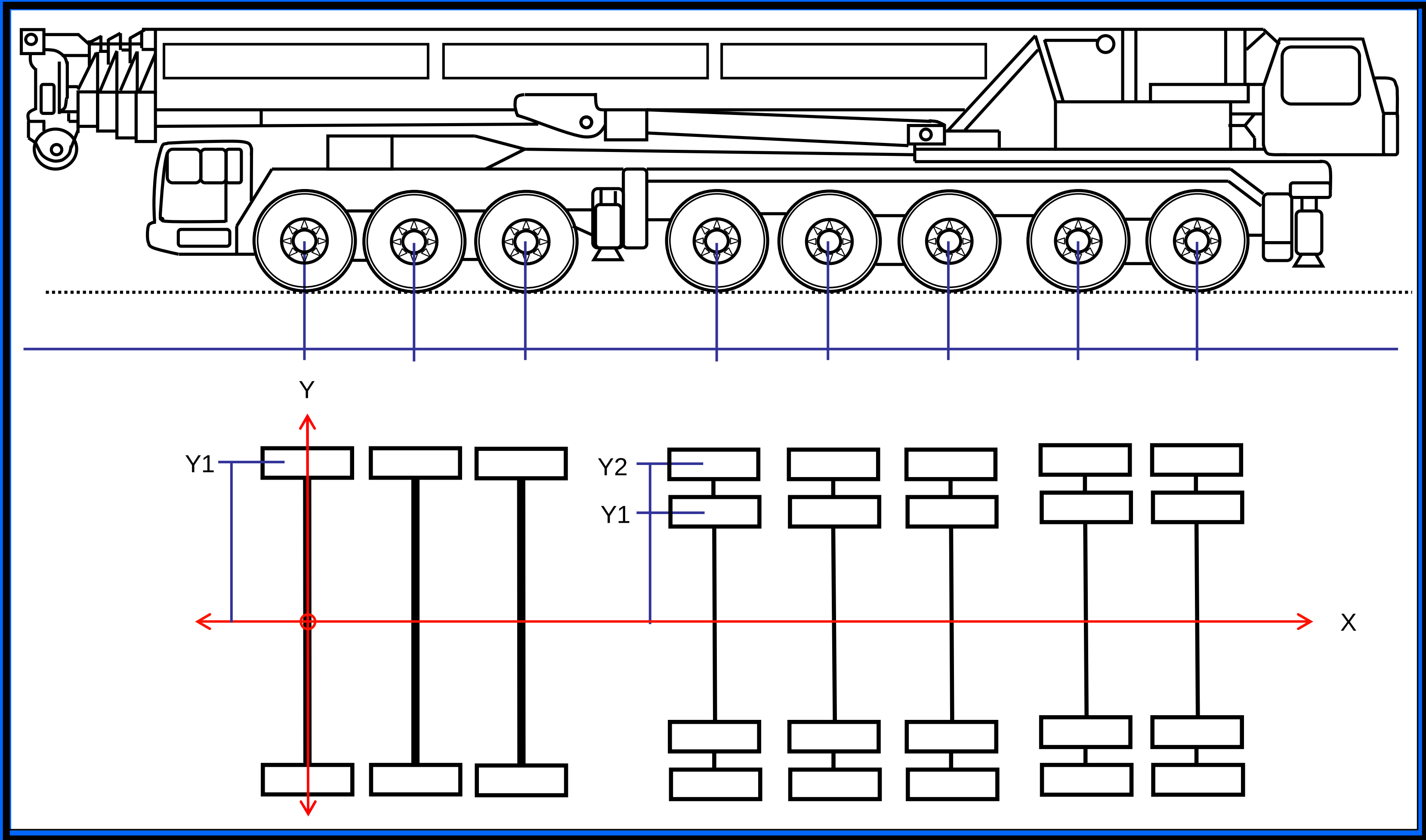
| Layer | Poisson's Ratio | Elastic Moduli (MPa) Phase I | Phase II | Phase III |
|---|---|---|---|---|
| S1* | 0.44 | 2000 | 1000 | 200 |
| 100 C4* | 0.35 | 2000 | 1500 | 100 |
| 100 C4* | 0.35 | 1000 | 300 | 100 |
| SUBGRADE | 0.35 | 140 | 140 | 100 |
| | - | - | - | - |

*** Classification according to TRH 14 (CSRA, 1985)**

# Mobile Cranes - Tyre Loading & Pressures……

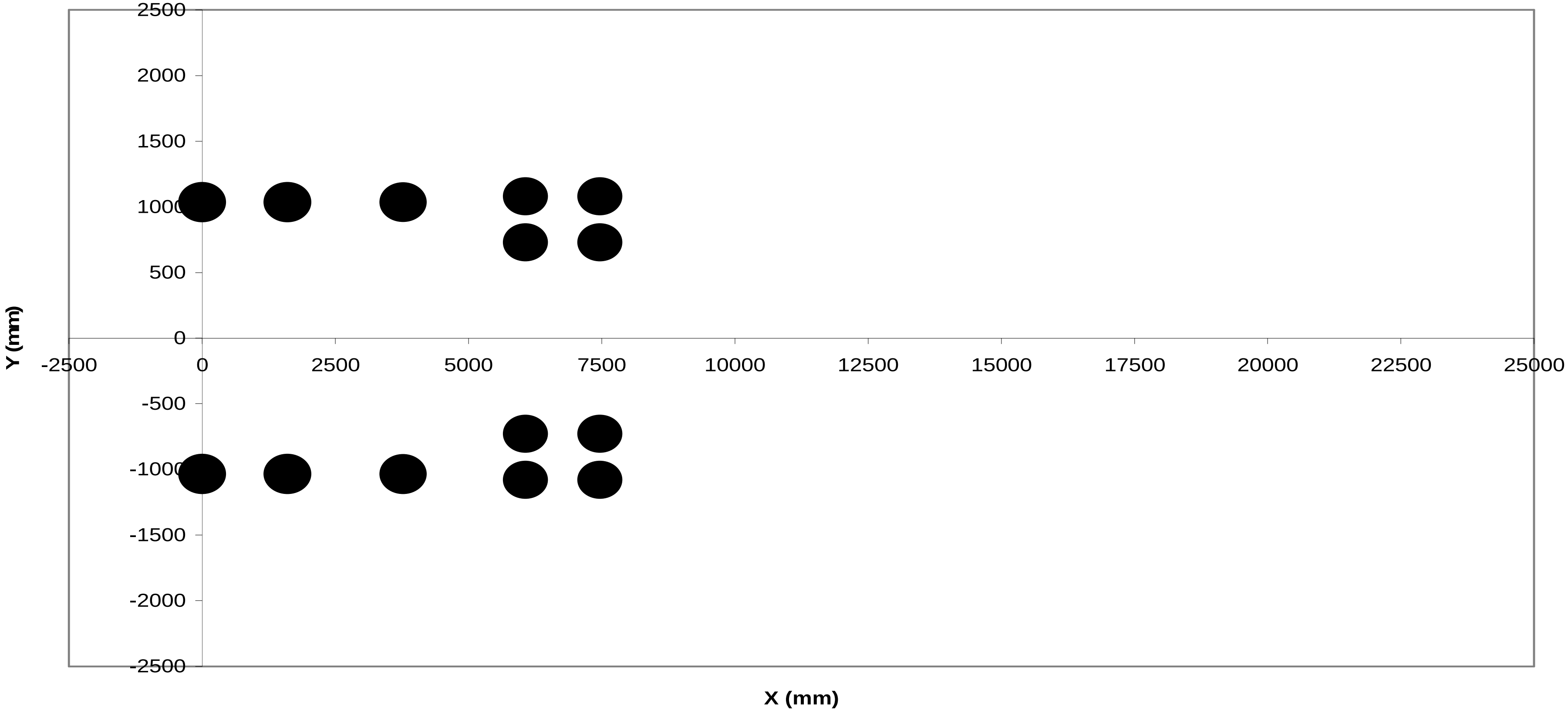
| MOBILE CRANES (SORTED ON AVE TYRE LOAD): | Average Tyre Load (kN) | Standard Deviation (kN) | Total Load (kN) | Number of Tyres | Average TiP (kPa) | Standard Deviation (kPa) |
|---|---|---|---|---|---|---|
| Crane - 4 Axle Single Dual tyres | 25.42 | 4.05 | 305.08 | 12 | 422.33 | 96.50 |
| Crane - 3 Axle Single Dual tyres | 25.72 | 2.83 | 257.24 | 10 | 434.00 | 65.35 |
| Crane - 6 Axle Single Dual tyres | 33.27 | 6.05 | 513.07 | 18 | 329.33 | 71.79 |
| Crane - 5 Axle Single Dual tyres | 36.32 | 1.98 | 508.50 | 14 | 695.00 | 13.00 |
| Crane - 2 Axle Single tyres | 56.26 | 0.74 | 225.04 | 4 | 664.50 | 12.12 |
| Crane - 3 Axle Single tyres | 56.93 | 1.24 | 341.58 | 6 | 494.67 | 14.46 |
| Crane - 6 Axle Single tyres | 59.38 | 2.22 | 712.60 | 12 | 523.00 | 17.76 |
| Crane - 7 Axle Single tyres | 60.65 | 0.61 | 849.08 | 14 | 537.71 | 7.03 |
| Crane - 8 Axle Single tyres | 60.65 | 1.86 | 970.44 | 16 | 537.25 | 21.15 |
| Crane - 4 Axle Single tyres | 64.01 | 5.77 | 512.08 | 8 | 524.50 | 59.33 |
| Crane - 5 Axle Single tyres | 65.00 | 7.05 | 650.02 | 10 | 586.60 | 79.46 |

# Mobile Cranes – Tyre/Axle Configurations……



# Mobile Cranes – Tyre/Axle Configurations……

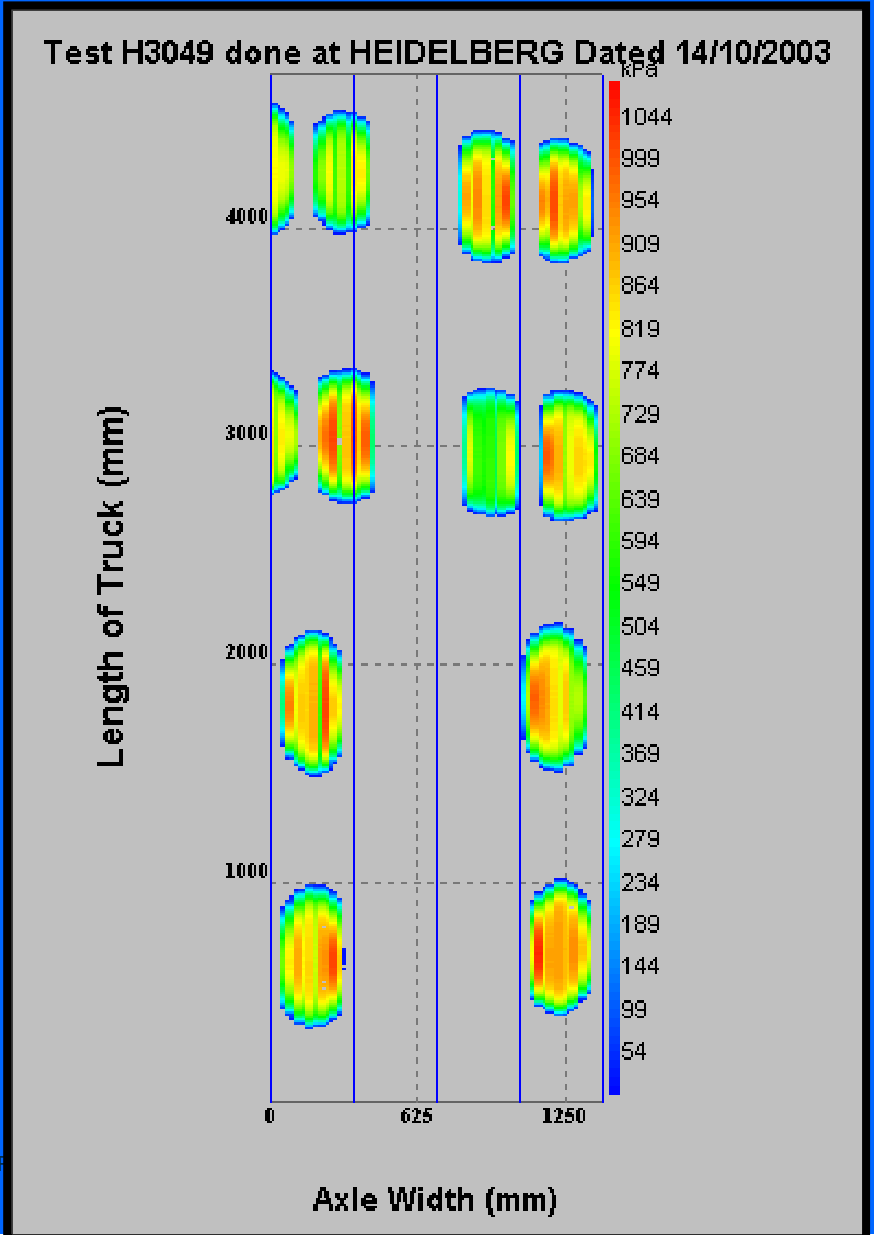
**Load Positions: Crane - 5 Axle Single Dual tyres**




| AV No. | Total Mass (kg) | Group No | Axle Type | Wheel Space A (mm) | Wheel Space B (mm) | Tyre Press | No. of Tyres | Axle No | Axle Mass | Tyre Mass | Tyre Load | Steer? | Dist. to Next Axle | Y1 (mm) | Y2 (mm) | X (mm) | Load (kN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GP403688 | 51832 | 1 | S | 2070 | | 678 | 2 | 1 | 7720 | 3860 | 37.9 | Yes | 1600 | 1035 | | 0 | 37.87 |
| | | | | | | | 2 | 2 | 7720 | 3860 | | Yes | 2170 | | | 1600 | 37.87 |
| | | 2 | S | 2070 | | 717 | 2 | 3 | 8072 | 4036 | 39.6 | Yes | 2300 | 1035 | | 3770 | 39.59 |
| | | 3 | D | 1460 | 350 | 698 | 4 | 4 | 14160 | 3540 | 34.7 | No | 1400 | 730 | 1080 | 6070 | 34.73 |
| | | | | | | | 4 | 5 | 14160 | 3540 | | No | 0 | | | 7470 | 34.73 |
| | | | | | | | **14** | | **51832** | | | | | | | | |

# Mobile Cranes – Tyre/Axle Footprint..

*Tyre Footprints….*

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# AVs - Tyre Loading & Pressures……

| ABNORMAL VEHICLES (SORTED ON AVE TYRE LOAD): | Average Tyre Load (kN) | Standard Deviation (kN) | Total Load (kN) | Number of Tyres | Average TiP (kPa) | Standard Deviation (kPa) |
|---|---|---|---|---|---|---|
| AV veh D - Abnormal Vehicle - 9 Axle Single Dual tyres (AVKN300146) | 16.59 | 5.34 | 962.00 | 58 | 736.52 | 4.29 |
| AV veh G - Abnormal Vehicle - 8 Axle Single Dual tyres (AVKN300177) | 17.57 | 4.47 | 878.40 | 50 | 463.68 | 209.46 |
| AV veh F - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305729) | 19.49 | 5.39 | 1130.60 | 58 | 494.66 | 162.10 |
| AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803) | 20.88 | 5.58 | 1211.20 | 58 | 573.52 | 80.22 |
| AV veh E - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305165) | 22.29 | 6.62 | 1292.80 | 58 | 624.48 | 1.14 |
| AV veh H - Abnormal Vehicle - 6 Axle Single tyres (AVFS100077) | 25.41 | 4.76 | 559.00 | 22 | 727.00 | 86.78 |
| AV veh B - Abnormal Vehicle - 7 Axle Single Dual tyres (AVNC100523) | 27.37 | 2.60 | 711.50 | 26 | 621.54 | 14.88 |
| AV veh A - Abnormal Vehicle - 6 Axle Single tyres (AVGP105343) | 29.23 | 1.80 | 643.00 | 22 | 625.18 | 29.20 |

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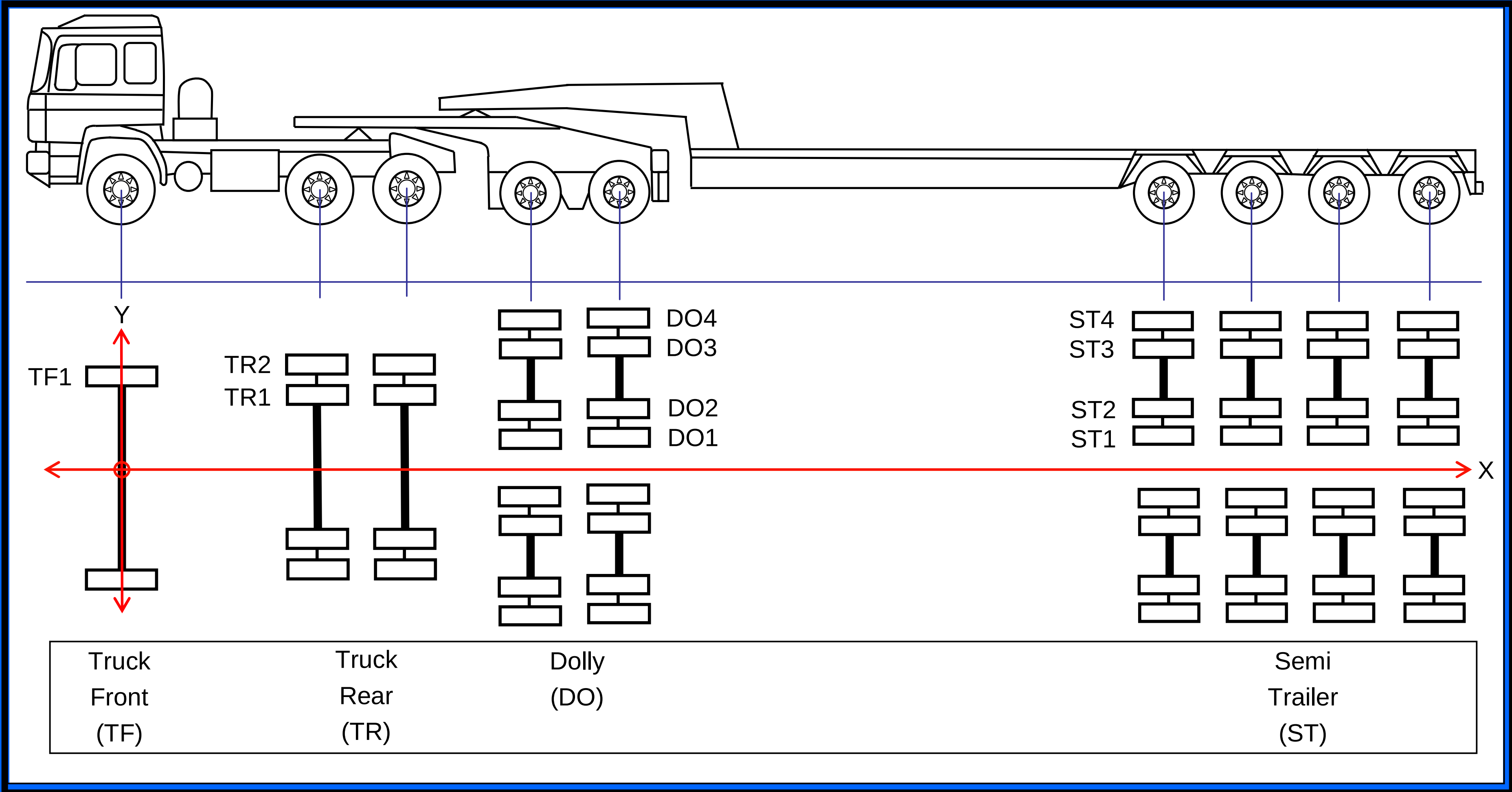
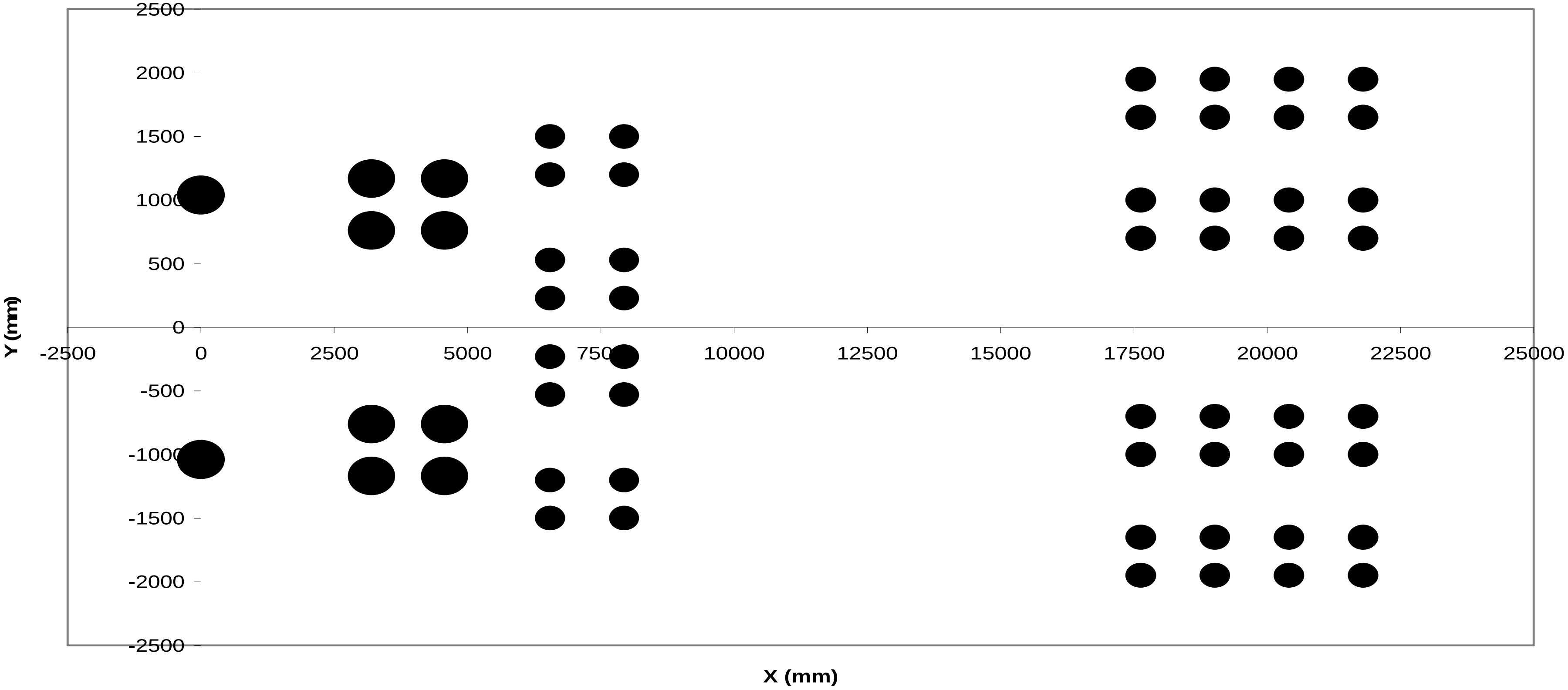
# AVs – Tyre/Axle Configurations……



# AVs – Tyre/Axle Configurations……

**Load Positions: AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803)**




| | | | | | | | | | | Y - Coordinates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Axle No | Group | | Group Mass | Tyre Mass | Tyre Load | Tyre Press. | Axle Type | X Coord | TF1 | TR1 | TR2 | DO1 | DO2 | DO3 | DO4 | ST1 | ST2 | ST3 | ST4 |
| AVGP304803 (C) | 1 | TF | 2 | 6684 | 3342 | 32.8 | 420 | S | 0 | 1040 | | | | | | | | | | |
| | 2 | TR | 8 | 26736 | 3342 | 32.8 | 435 | D | 3200 | | 760 | 1170 | | | | | | | | |
| | 3 | | | | | | | | 4570 | | | | | | | | | | | |
| | 4 | DO | 16 | 32584 | 2037 | 20.0 | 675 | 4D | 6550 | | | | 230 | 530 | 1200 | 1500 | | | | |
| | 5 | | | | | | | | 7940 | | | | | | | | | | | |
| | 6 | ST | 32 | 57496 | 1797 | 17.6 | 567 | 4D | 17630 | | | | | | | | 700 | 1000 | 1650 | 1950 |
| | 7 | | | | | | | | 19020 | | | | | | | | | | | |
| | 8 | | | | | | | | 20410 | | | | | | | | | | | |
| | 9 | | | | | | | | 21800 | | | | | | | | | | | |
| | | | 58 | 123500 | | | | | | | | | | | | | | | | |

# Definition of Road Damage Factors (this paper)

- Legal Damage (LDv);
- Total Damage (TDv);
- Total Additional Damage (TADv);



# Legal Damage (LDv)……

$$Legal\ Damage\ of\ Vehicle = LD_V = \sum_{i=1}^{n} \frac{(Ncritical\ from\ Legal\ 88\ kN/700\ kPa\ Axle)}{(Ncritical\ from\ Standard\ 80\ kN/520\ kPa\ Axle_i\ )} ......Eq\ 1.0$$

*or*

$$LD_V = n\ x \left[ \frac{(Ncritical\ from\ Legal\ 88\ kN/700\ kPa\ Axle)}{(Ncritical\ from\ Standard\ 80\ kN/520\ kPa\ Axle)} \right] ..........................................Eq.1.1$$

*where:*

- *n = number of axles on Vehicle (v).*
- *Ncritical from Legal 88 kN/700 kPa Axle = Minimum layer life of pavement under the loading of the current Legal Axle of 88 kN and 700 kPa inflation pressure on 4 tyres (i.e. 22 kN per tyre @ 700 kPa contact stress (= inflation pressure)).*
- *Ncritical from Standard 80 kN/520 kPa Axle = Minimum layer life of pavement under the loading of the Standard Axle of 80 kN and 520 kPa inflation pressure on 4 tyres (i.e. 20 kN per tyre @ 520 kPa contact stress (= inflation pressure)).*

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# Total Damage (TDv)……….

$$LEF_V = Total\ Damage\ of\ Vehicle = TD_V = \sum_{i=1}^{n} \frac{(Ncritical\ from\ Standard\ 80\ kN/520\ kPa\ Axle)}{(Ncritical\ from\ Axle_i\ )} \text{........Eq 2.0}$$

*where:*

- *n = number of axles on vehicle.*
- *Ncritical from Standard 80 kN/520 kPa Axle = Minimum layer life of pavement under the loading of the Standard Axle of 80 kN and 520 kPa inflation pressure on 4 tyres (i.e. 20 kN per tyre @ 520 kPa contact stress (= inflation pressure)).*
- *Ncritical from Axle$_i$ = Minimum layer life of pavement under the loading of Axle$_i$ of vehicle in question.*

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# Total Additional Damage (TADv)………..

*Total Additional Damage of Vehicle* $= TAD_v$

$$= \left[ \sum_{i=1}^{n} \left[ \frac{\text{(Ncritical from Standard 80 kN/520 kPa Axle)}}{\text{(Ncritical from Axle}_i\text{)}} \right] - \sum_{i=1}^{n} \left[ \frac{\text{(Ncritical from Legal 88 kN/700 kPa Axle)}}{\text{(Ncritical from Standard 80 kN/520 kPa Axle}_i\text{)}} \right] \right]$$

$$= \left[ TD_V - LD_v \right] \qquad \text{Eq 3.0}$$

*where:*

- $n$ = *number of axles on Vehicle (v).*
- $LD_v$ = *Legal Damage of Vehicle (v), and*
- $TD_v$ = *Total Damage of Vehicle (v)* = $LEF_v$

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# Load Equivalency Factors (LEFv)...

$$N_{cAV} = Critical \quad Pavement \quad Life \quad of \quad AV;$$

$$N_{std} = Pavement \quad Bearing \quad Capacity \quad on \quad per$$

$$axle \quad basis - under \quad a \quad standard \quad 80kN / 520kPa$$

$$axle \quad load \ (4 \, tyres);$$

$$LEFv = \frac{N_{std}}{N_{cAV}}, \quad LEFv > 1.0;$$

$$N_{cAV} = LEFv * N_{std}$$

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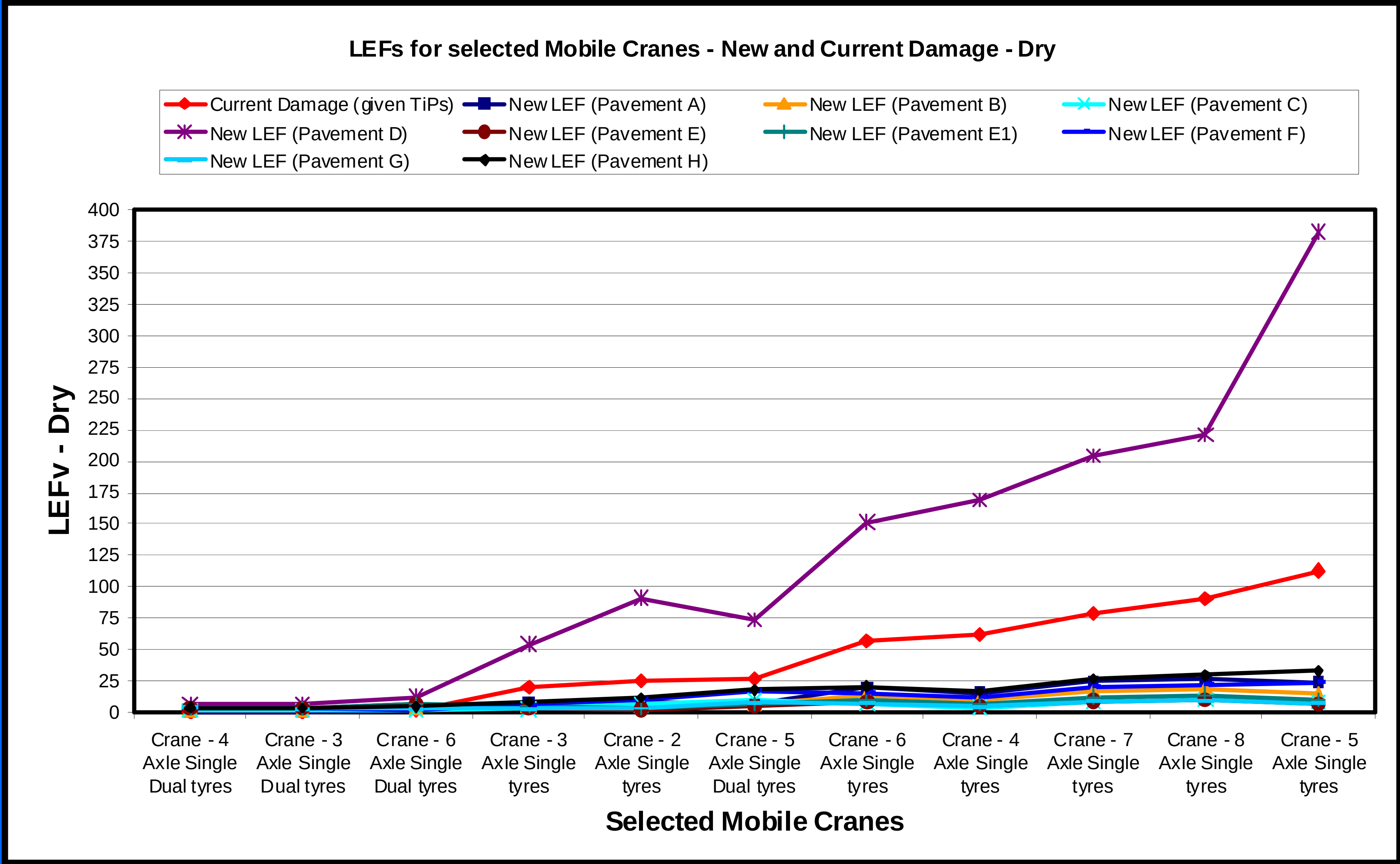
# (LEFs)... Cranes - DRY Pavements

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | New LEF (Pavement A) | New LEF (Pavement B) | New LEF (Pavement C) | New LEF (Pavement D) | New LEF (Pavement E) | New LEF (Pavement E1) | New LEF (Pavement F) | New LEF (Pavement G) | New LEF (Pavement H) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside | DRY | Crane - 4 Axle Single Dual tyres | 0.1 | 0.5 | 1.9 | 2.3 | 6.9 | 3.8 | 3.7 | 3.6 | 3.9 | 4.0 |
| Outside | DRY | Crane - 3 Axle Single Dual tyres | 0.7 | 0.5 | 1.7 | 1.8 | 6.5 | 2.9 | 3.0 | 3.0 | 3.0 | 3.4 |
| Outside | DRY | Crane - 6 Axle Single Dual tyres | 1.6 | 1.5 | 3.4 | 1.5 | 12.7 | 6.2 | 6.1 | 2.6 | 2.9 | 4.6 |
| Outside | DRY | Crane - 3 Axle Single tyres | 20.3 | 8.0 | 5.8 | 2.8 | 54.5 | 3.6 | 4.7 | 6.1 | 3.2 | 8.4 |
| Outside | DRY | Crane - 2 Axle Single tyres | 24.6 | 8.2 | 4.7 | 6.2 | 91.1 | 2.5 | 3.5 | 10.5 | 3.4 | 12.1 |
| Outside | DRY | Crane - 5 Axle Single Dual tyres | 26.8 | 7.1 | 6.8 | 9.5 | 73.6 | 5.4 | 6.5 | 17.6 | 7.9 | 17.9 |
| Outside | DRY | Crane - 6 Axle Single tyres | 57.6 | 19.4 | 13.7 | 6.8 | 151.4 | 7.7 | 10.5 | 15.5 | 6.9 | 21.0 |
| Outside | DRY | Crane - 4 Axle Single tyres | 62.4 | 15.8 | 10.4 | 4.2 | 168.9 | 5.3 | 7.5 | 12.0 | 4.5 | 17.2 |
| Outside | DRY | Crane - 7 Axle Single tyres | 78.3 | 24.9 | 16.8 | 8.7 | 204.4 | 9.1 | 12.6 | 20.4 | 8.5 | 27.2 |
| Outside | DRY | Crane - 8 Axle Single tyres | 91.0 | 27.1 | 18.7 | 10.0 | 221.2 | 10.5 | 14.2 | 22.0 | 9.5 | 29.5 |
| Outside | DRY | Crane - 5 Axle Single tyres | 113.1 | 24.1 | 14.4 | 8.6 | 382.1 | 6.7 | 10.0 | 24.2 | 7.1 | 33.0 |

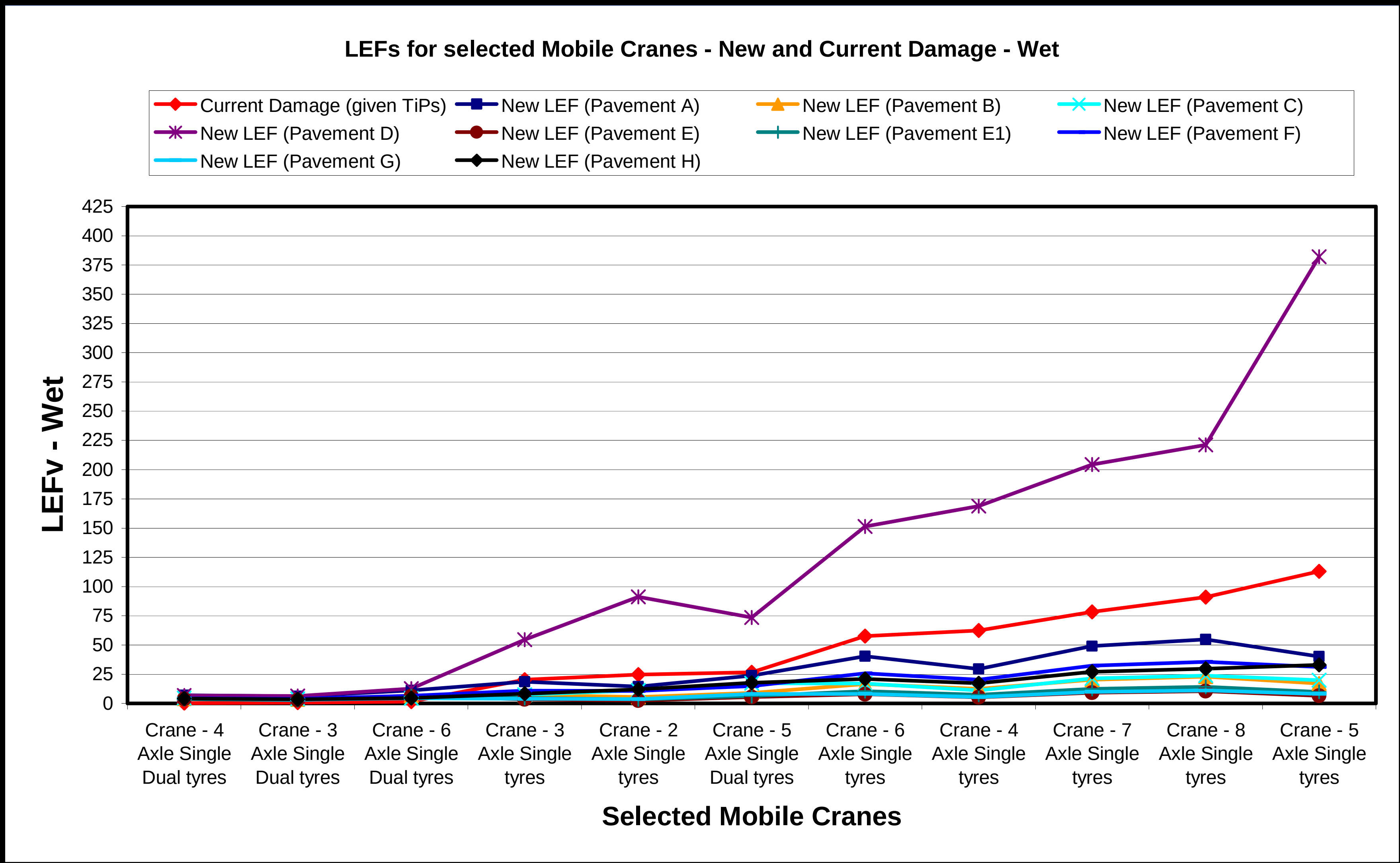
# (LEFs)... Cranes - DRY Pavements



# (LEFs)... Cranes - WET Pavements

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | New LEF (Pavement A) | New LEF (Pavement B) | New LEF (Pavement C) | New LEF (Pavement D) | New LEF (Pavement E) | New LEF (Pavement E1) | New LEF (Pavement F) | New LEF (Pavement G) | New LEF (Pavement H) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside | WET | Crane - 4 Axle Single Dual tyres | 0.1 | 7.0 | 4.1 | 4.8 | 6.9 | 3.8 | 3.7 | 4.5 | 4.1 | 4.0 |
| Outside | WET | Crane - 3 Axle Single Dual tyres | 0.7 | 6.2 | 3.5 | 3.9 | 6.5 | 2.9 | 3.0 | 3.8 | 3.2 | 3.4 |
| Outside | WET | Crane - 6 Axle Single Dual tyres | 1.6 | 11.2 | 6.6 | 4.4 | 12.7 | 6.2 | 6.1 | 6.6 | 4.5 | 4.7 |
| Outside | WET | Crane - 3 Axle Single tyres | 20.3 | 18.5 | 7.2 | 7.3 | 54.5 | 3.6 | 4.7 | 11.0 | 3.8 | 8.4 |
| Outside | WET | Crane - 2 Axle Single tyres | 24.6 | 14.5 | 5.5 | 11.1 | 91.1 | 2.5 | 3.5 | 10.7 | 3.6 | 12.1 |
| Outside | WET | Crane - 5 Axle Single Dual tyres | 26.8 | 23.8 | 9.0 | 17.1 | 73.6 | 5.4 | 6.5 | 14.9 | 8.0 | 17.9 |
| Outside | WET | Crane - 6 Axle Single tyres | 57.6 | 40.5 | 16.6 | 16.9 | 151.4 | 7.7 | 10.5 | 25.7 | 8.2 | 21.0 |
| Outside | WET | Crane - 4 Axle Single tyres | 62.4 | 29.5 | 12.4 | 11.1 | 168.9 | 5.3 | 7.5 | 20.4 | 5.6 | 17.2 |
| Outside | WET | Crane - 7 Axle Single tyres | 78.3 | 49.0 | 20.2 | 21.4 | 204.4 | 9.1 | 12.6 | 32.3 | 10.0 | 27.2 |
| Outside | WET | Crane - 8 Axle Single tyres | 91.0 | 54.8 | 22.8 | 23.7 | 221.2 | 10.5 | 14.2 | 35.5 | 11.1 | 29.7 |
| Outside | WET | Crane - 5 Axle Single tyres | 113.1 | 40.2 | 16.9 | 19.9 | 382.1 | 6.7 | 10.0 | 31.3 | 8.2 | 33.0 |

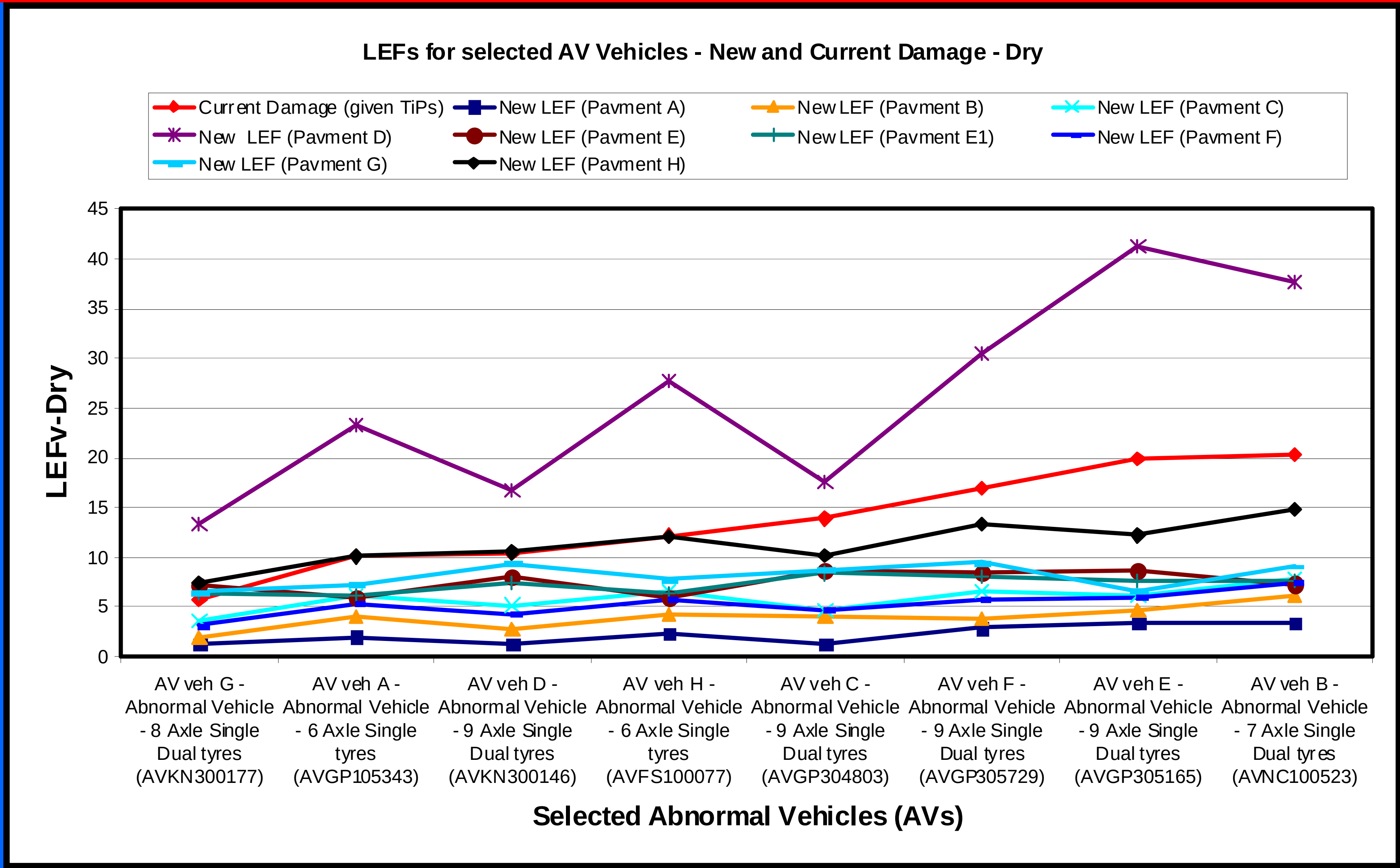
# (LEFs)... Cranes - WET Pavements



# (LEFs)... AVs - DRY Pavements

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | New LEF (Pavement A) | New LEF (Pavement B) | New LEF (Pavement C) | New LEF (Pavement D) | New LEF (Pavement E) | New LEF (Pavement E1) | New LEF (Pavement F) | New LEF (Pavement G) | New LEF (Pavement H) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside | DRY | AV veh G - Abnormal Vehicle - 8 Axle Single Dual tyres (AVKN300177) | 5.8 | 1.3 | 2.0 | 3.7 | 13.4 | 7.2 | 6.3 | 3.1 | 6.5 | 7.4 |
| Outside | DRY | AV veh A - Abnormal Vehicle - 6 Axle Single tyres (AVGP105343) | 10.2 | 2.0 | 4.1 | 6.1 | 23.3 | 5.9 | 6.1 | 5.4 | 7.3 | 10.1 |
| Outside | DRY | AV veh D - Abnormal Vehicle - 9 Axle Single Dual tyres (AVKN300146) | 10.3 | 1.3 | 2.8 | 5.2 | 16.7 | 8.1 | 7.4 | 4.3 | 9.4 | 10.5 |
| Outside | DRY | AV veh H - Abnormal Vehicle - 6 Axle Single tyres (AVFS100077) | 12.2 | 2.4 | 4.3 | 6.6 | 27.7 | 5.9 | 6.3 | 5.8 | 7.8 | 12.0 |
| Outside | DRY | AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803) | 13.9 | 1.3 | 4.0 | 4.7 | 17.6 | 8.6 | 8.4 | 4.7 | 8.8 | 10.2 |
| Outside | DRY | AV veh F - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305729) | 16.9 | 2.9 | 3.9 | 6.6 | 30.5 | 8.4 | 8.1 | 5.8 | 9.5 | 13.3 |
| Outside | DRY | AV veh E - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305165) | 19.8 | 3.4 | 4.7 | 6.1 | 41.2 | 8.6 | 7.6 | 6.0 | 6.7 | 12.2 |
| Outside | DRY | AV veh B - Abnormal Vehicle - 7 Axle Single Dual tyres (AVNC100523) | 20.3 | 3.4 | 6.1 | 7.8 | 37.6 | 7.3 | 7.7 | 7.5 | 9.1 | 14.8 |

# (LEFs)... AVs - DRY Pavements

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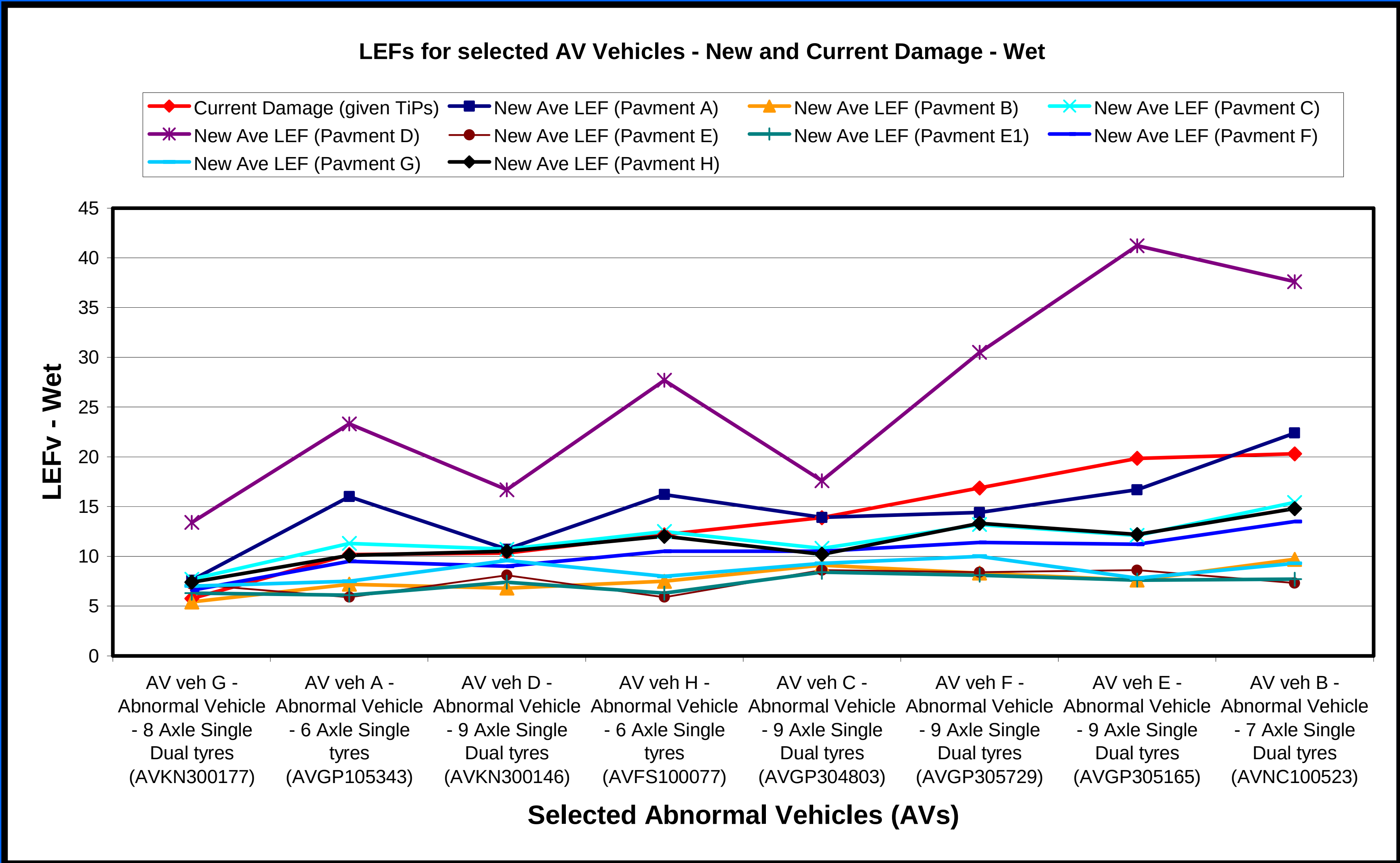
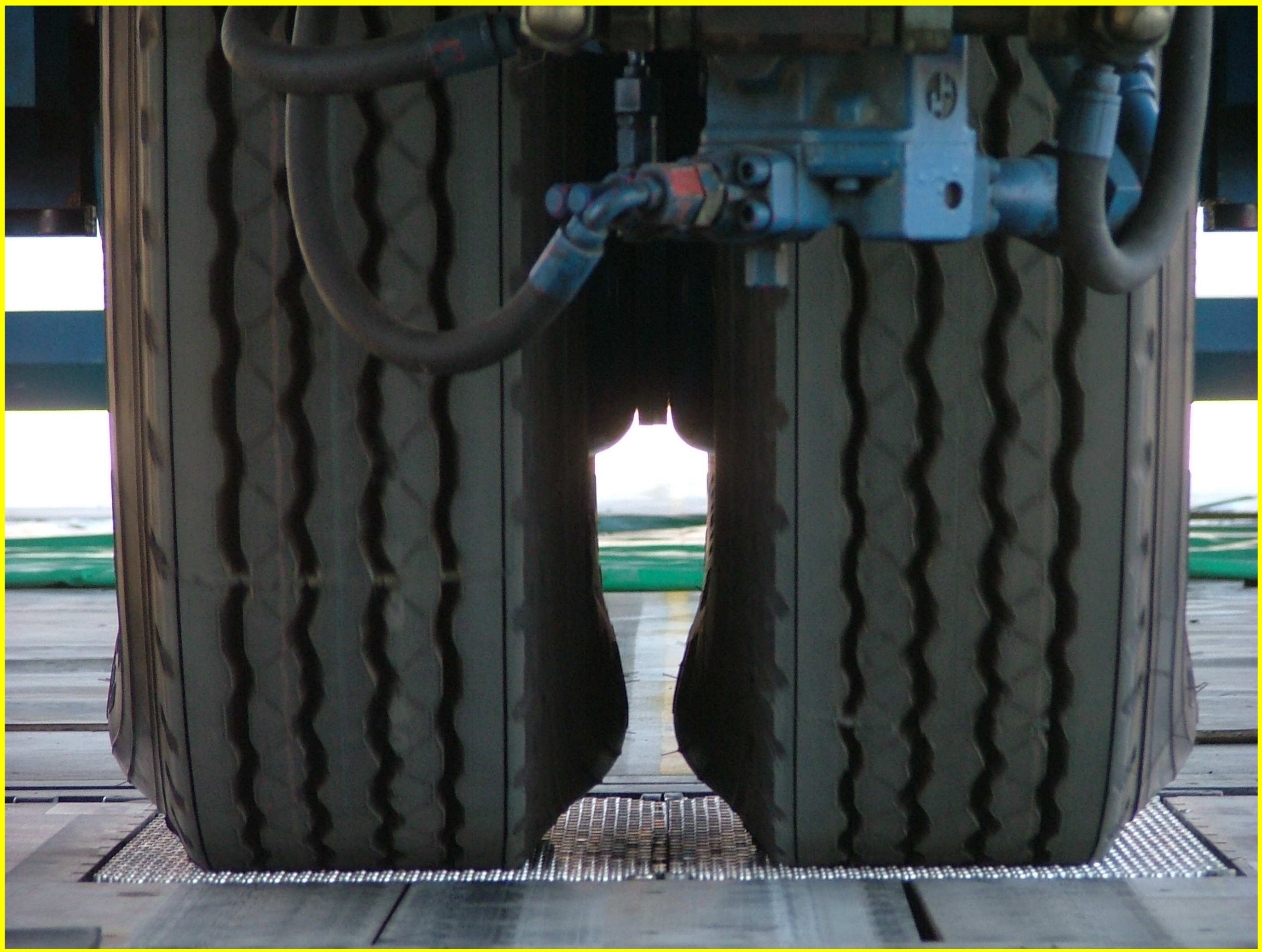
# (LEFs)... AVs – WET Pavements

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | New LEF (Pavement A) | New LEF (Pavement B) | New LEF (Pavement C) | New LEF (Pavement D) | New LEF (Pavement E) | New LEF (Pavement E1) | New LEF (Pavement F) | New LEF (Pavement G) | New LEF (Pavement H) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside | WET | AV veh G - Abnormal Vehicle - 8 Axle Single Dual tyres (AVKN300177) | 5.8 | 7.6 | 5.4 | 7.7 | 13.4 | 7.2 | 6.3 | 6.6 | 7.0 | 7.4 |
| Outside | WET | AV veh A - Abnormal Vehicle - 6 Axle Single tyres (AVGP105343) | 10.2 | 16.0 | 7.2 | 11.3 | 23.3 | 5.9 | 6.1 | 9.5 | 7.5 | 10.1 |
| Outside | WET | AV veh D - Abnormal Vehicle - 9 Axle Single Dual tyres (AVKN300146) | 10.3 | 10.7 | 6.8 | 10.7 | 16.7 | 8.1 | 7.4 | 9.0 | 9.6 | 10.5 |
| Outside | WET | AV veh H - Abnormal Vehicle - 6 Axle Single tyres (AVFS100077) | 12.2 | 16.2 | 7.5 | 12.5 | 27.7 | 5.9 | 6.3 | 10.5 | 8.0 | 12.0 |
| Outside | WET | AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803) | 13.9 | 13.9 | 9.1 | 10.8 | 17.6 | 8.6 | 8.4 | 10.5 | 9.3 | 10.2 |
| Outside | WET | AV veh F - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305729) | 16.9 | 14.4 | 8.3 | 13.2 | 30.5 | 8.4 | 8.1 | 11.4 | 10.0 | 13.3 |
| Outside | WET | AV veh E - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305165) | 19.8 | 16.7 | 7.6 | 12.1 | 41.2 | 8.6 | 7.6 | 11.2 | 7.8 | 12.2 |
| Outside | WET | AV veh B - Abnormal Vehicle - 7 Axle Single Dual tyres (AVNC100523) | 20.3 | 22.4 | 9.7 | 15.4 | 37.6 | 7.3 | 7.7 | 13.5 | 9.3 | 14.8 |

# (LEFs)... AVs – WET Pavements



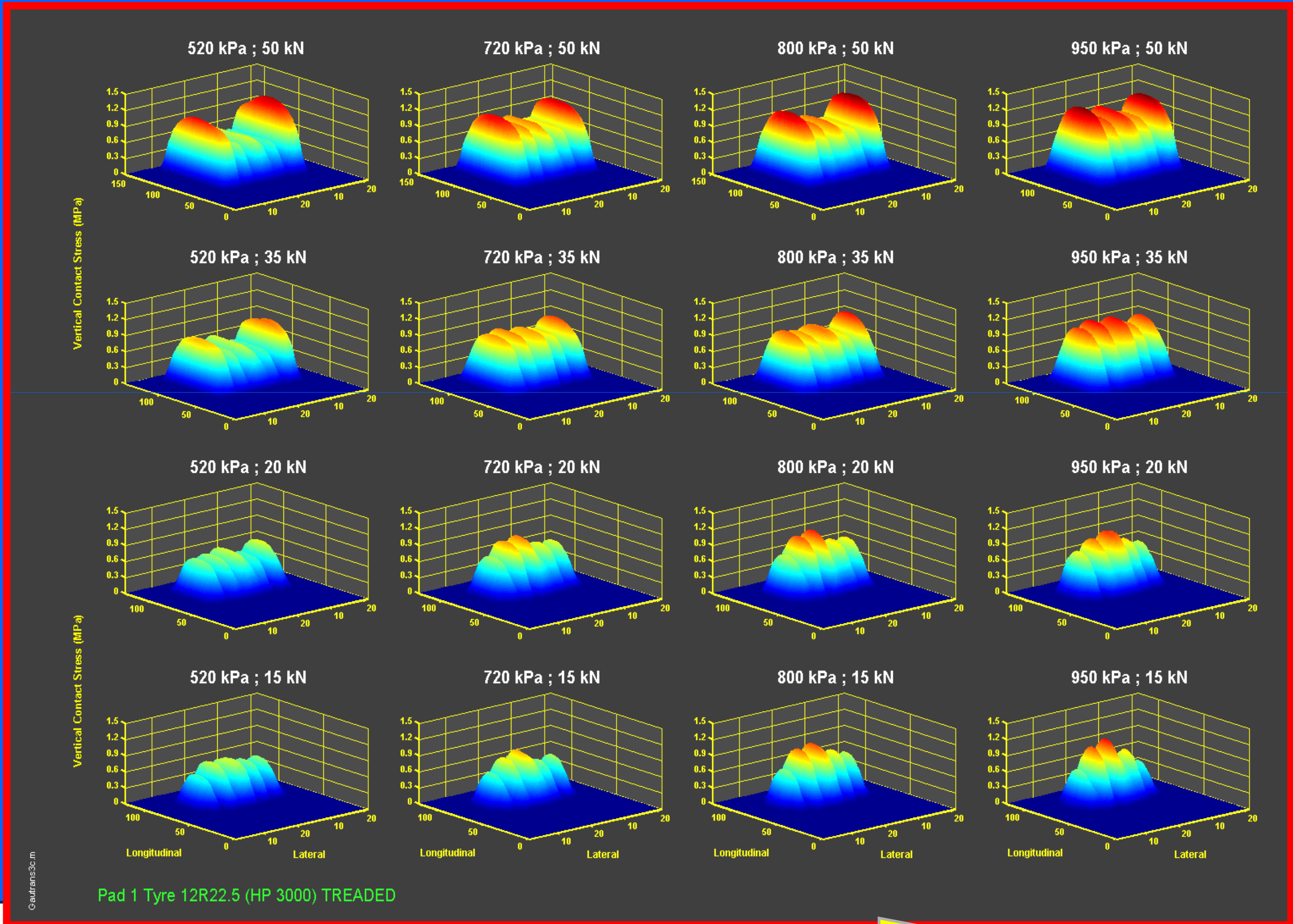
# HEAVY VEHICLE SIMULATOR (HVS) DUAL TEST TYRES (12R22.5)





# "FINGER PRINTING" - VERTICAL CONTACT STRESS (HVS 12R22.5)



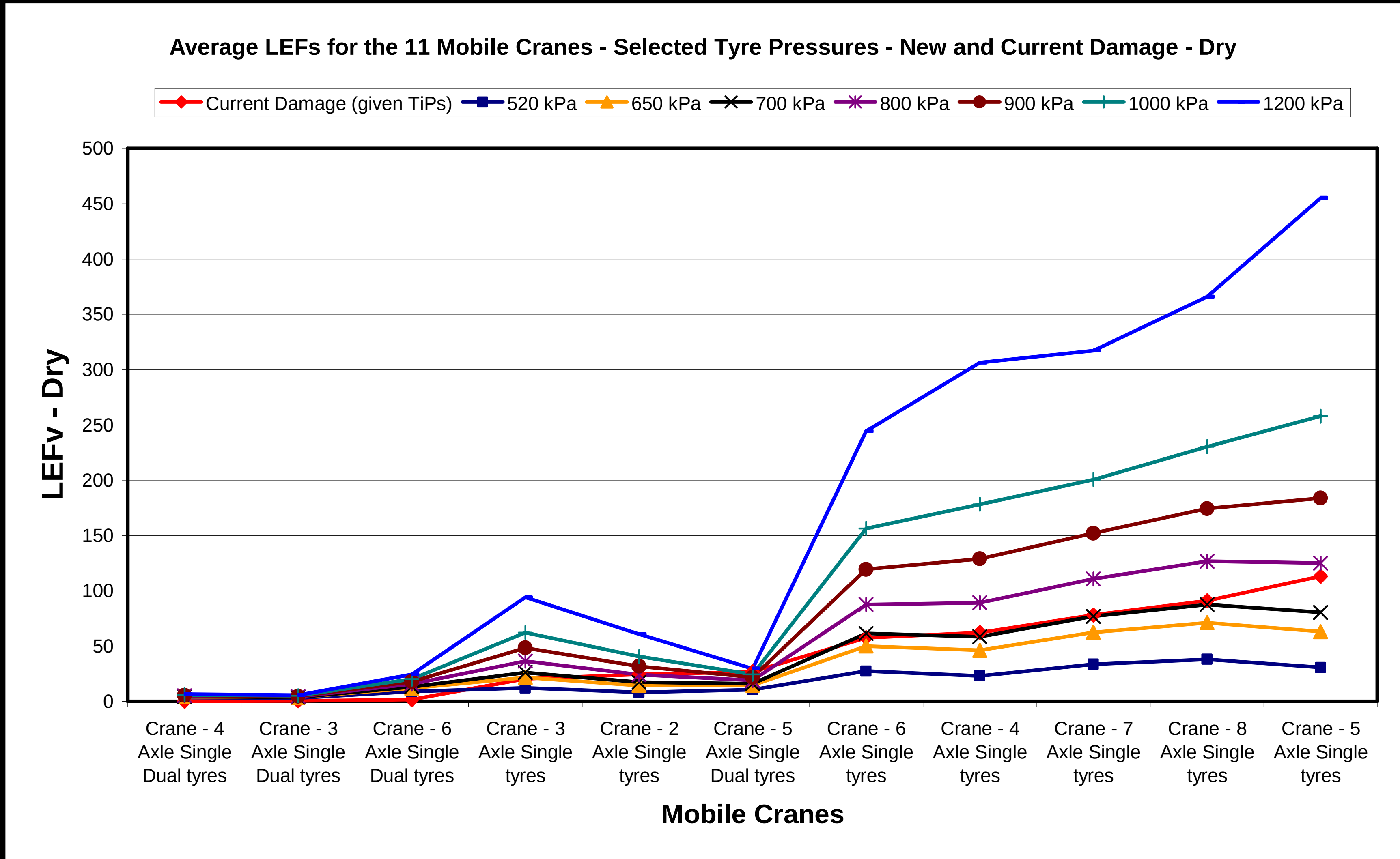

TYRE LOAD

INFLATION PRESSURE

# Heavy Vehicles - Road Users:

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | 520 kPa | 650 kPa | 700 kPa | 800 kPa | 900 kPa | 1000 kPa | 1200 kPa |
|---|---|---|---|---|---|---|---|---|---|---|
| Outside | DRY | Crane - 4 Axle Single Dual tyres | 0.11 | 3.59 | 4.35 | 4.61 | 5.10 | 5.54 | 5.93 | 6.60 |
| Outside | DRY | Crane - 3 Axle Single Dual tyres | 0.65 | 3.12 | 3.78 | 4.01 | 4.43 | 4.81 | 5.15 | 5.73 |
| Outside | DRY | Crane - 6 Axle Single Dual tyres | 1.64 | 8.89 | 12.04 | 13.25 | 15.66 | 18.01 | 20.30 | 24.64 |
| Outside | DRY | Crane - 3 Axle Single tyres | 20.34 | 12.26 | 21.77 | 26.26 | 36.52 | 48.59 | 62.32 | 94.00 |
| Outside | DRY | Crane - 2 Axle Single tyres | 24.64 | 8.26 | 14.54 | 17.43 | 24.09 | 31.87 | 40.67 | 60.78 |
| Outside | DRY | Crane - 5 Axle Single Dual tyres | 26.76 | 10.69 | 14.59 | 16.09 | 19.04 | 21.89 | 24.62 | 29.69 |
| Outside | DRY | Crane - 6 Axle Single tyres | 57.57 | 27.36 | 50.23 | 61.47 | 87.73 | 119.41 | 156.34 | 244.38 |
| Outside | DRY | Crane - 4 Axle Single tyres | 62.42 | 23.14 | 46.30 | 58.56 | 89.35 | 129.07 | 178.37 | 306.31 |
| Outside | DRY | Crane - 7 Axle Single tyres | 78.31 | 33.57 | 62.49 | 76.92 | 110.83 | 152.08 | 200.55 | 317.18 |
| Outside | DRY | Crane - 8 Axle Single tyres | 90.95 | 38.18 | 71.23 | 87.75 | 126.74 | 174.29 | 230.33 | 365.80 |
| Outside | DRY | Crane - 5 Axle Single tyres | 113.08 | 30.76 | 63.05 | 80.46 | 125.01 | 183.79 | 257.99 | 455.32 |

# Heavy Vehicles - Road Users:

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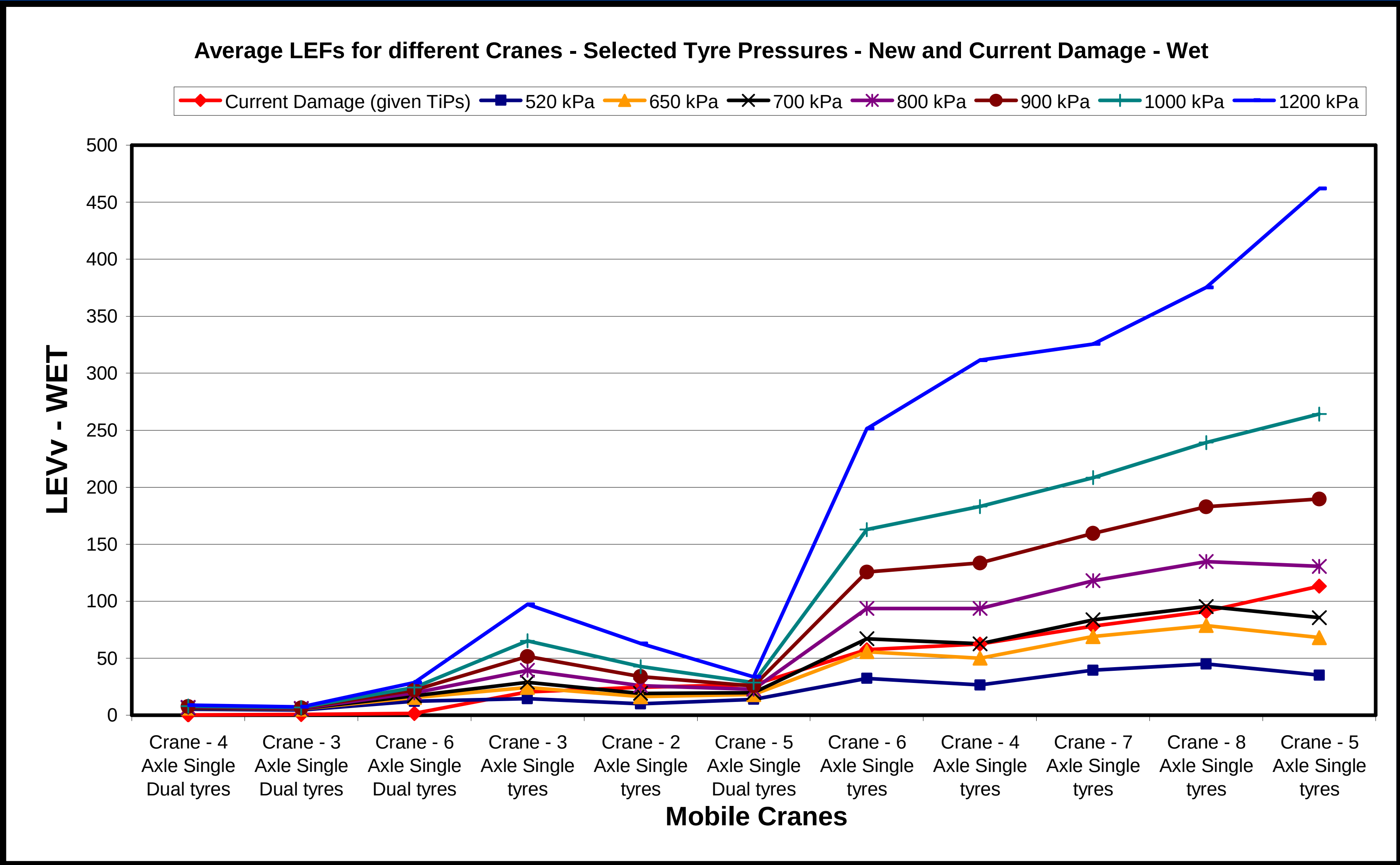
# Heavy Vehicles - Road Users:

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | 520 kPa | 650 kPa | 700 kPa | 800 kPa | 900 kPa | 1000 kPa | 1200 kPa |
|---|---|---|---|---|---|---|---|---|---|---|
| Outside | WET | Crane - 4 Axle Single Dual tyres | 0.11 | 5.24 | 6.15 | 6.46 | 7.02 | 7.52 | 7.96 | 8.70 |
| Outside | WET | Crane - 3 Axle Single Dual tyres | 0.65 | 4.52 | 5.31 | 5.57 | 6.05 | 6.48 | 6.85 | 7.48 |
| Outside | WET | Crane - 6 Axle Single Dual tyres | 1.64 | 12.24 | 15.65 | 16.94 | 19.47 | 21.93 | 24.30 | 28.77 |
| Outside | WET | Crane - 3 Axle Single tyres | 20.34 | 14.67 | 24.37 | 28.93 | 39.32 | 51.51 | 65.35 | 97.23 |
| Outside | WET | Crane - 2 Axle Single tyres | 24.64 | 9.90 | 16.30 | 19.23 | 25.98 | 33.83 | 42.70 | 62.94 |
| Outside | WET | Crane - 5 Axle Single Dual tyres | 26.76 | 14.02 | 18.15 | 19.71 | 22.77 | 25.70 | 28.50 | 33.68 |
| Outside | WET | Crane - 6 Axle Single tyres | 57.57 | 32.40 | 55.72 | 67.13 | 93.68 | 125.63 | 162.81 | 251.29 |
| Outside | WET | Crane - 4 Axle Single tyres | 62.42 | 26.62 | 50.17 | 62.59 | 93.66 | 133.61 | 183.11 | 311.39 |
| Outside | WET | Crane - 7 Axle Single tyres | 78.31 | 39.51 | 69.01 | 83.64 | 117.92 | 159.51 | 208.28 | 325.46 |
| Outside | WET | Crane - 8 Axle Single tyres | 90.95 | 44.96 | 78.66 | 95.42 | 134.82 | 182.76 | 239.15 | 375.24 |
| Outside | WET | Crane - 5 Axle Single tyres | 113.08 | 35.15 | 67.97 | 85.59 | 130.53 | 189.63 | 264.10 | 461.88 |

# Heavy Vehicles - Road Users:

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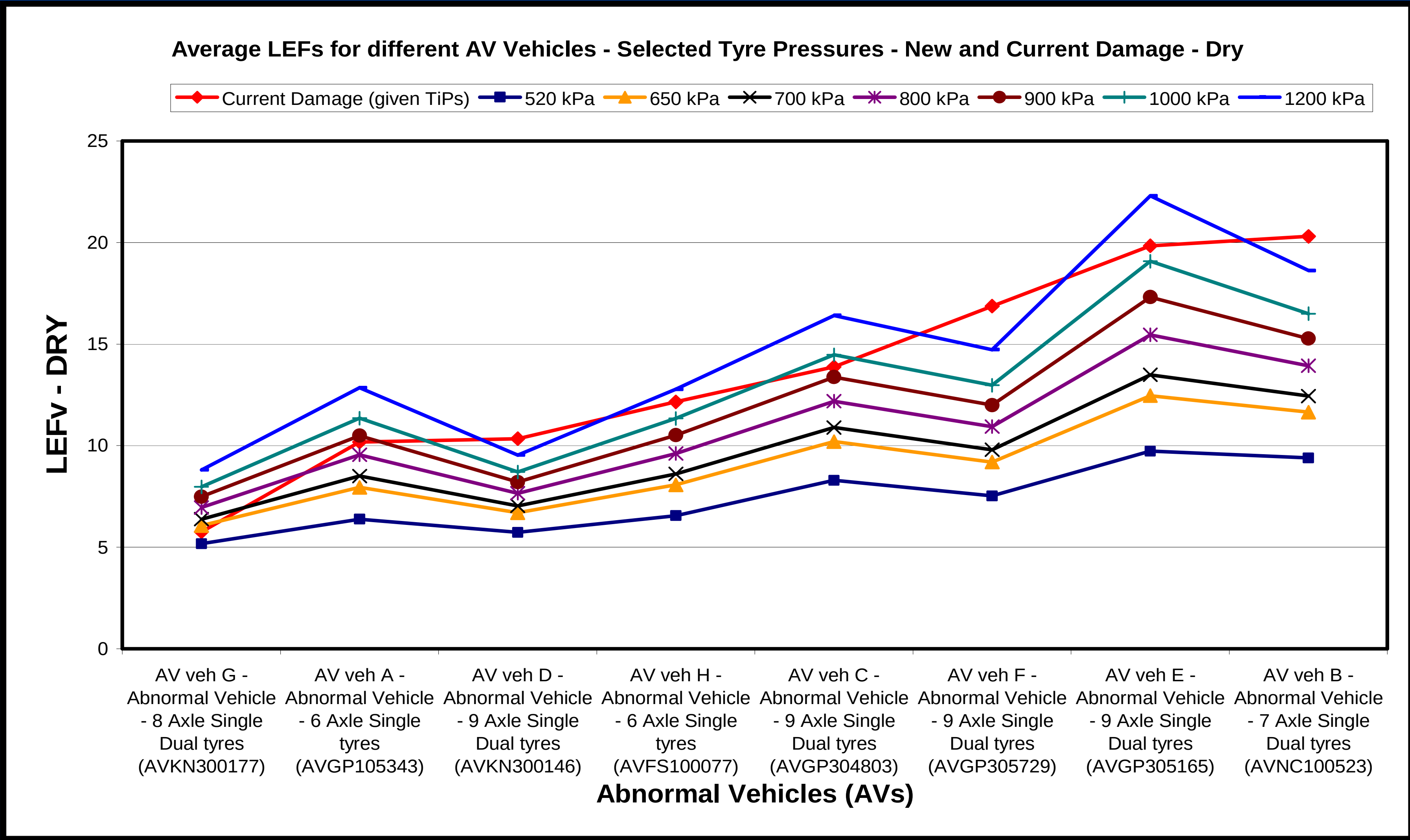
# Heavy Vehicles - Road Users:

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | 520 kPa | 650 kPa | 700 kPa | 800 kPa | 900 kPa | 1000 kPa | 1200 kPa |
|---|---|---|---|---|---|---|---|---|---|---|
| Outside | DRY | AV veh G - Abnormal Vehicle - 8 Axle Single Dual tyres (AVKN300177) | 5.76 | 5.17 | 6.07 | 6.38 | 6.96 | 7.49 | 7.97 | 8.81 |
| Outside | DRY | AV veh A - Abnormal Vehicle - 6 Axle Single tyres (AVGP105343) | 10.18 | 6.38 | 7.95 | 8.51 | 9.55 | 10.49 | 11.35 | 12.85 |
| Outside | DRY | AV veh D - Abnormal Vehicle - 9 Axle Single Dual tyres (AVKN300146) | 10.34 | 5.73 | 6.70 | 7.04 | 7.66 | 8.21 | 8.70 | 9.53 |
| Outside | DRY | AV veh H - Abnormal Vehicle - 6 Axle Single tyres (AVFS100077) | 12.16 | 6.56 | 8.07 | 8.61 | 9.61 | 10.52 | 11.34 | 12.78 |
| Outside | DRY | AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803) | 13.88 | 8.29 | 10.20 | 10.89 | 12.19 | 13.38 | 14.48 | 16.41 |
| Outside | DRY | AV veh F - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305729) | 16.87 | 7.53 | 9.19 | 9.79 | 10.93 | 11.99 | 12.97 | 14.73 |
| Outside | DRY | AV veh E - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305165) | 19.84 | 9.74 | 12.46 | 13.48 | 15.45 | 17.31 | 19.08 | 22.29 |
| Outside | DRY | AV veh B - Abnormal Vehicle - 7 Axle Single Dual tyres (AVNC100523) | 20.30 | 9.40 | 11.64 | 12.44 | 13.93 | 15.27 | 16.49 | 18.61 |

# Heavy Vehicles - Road Users:

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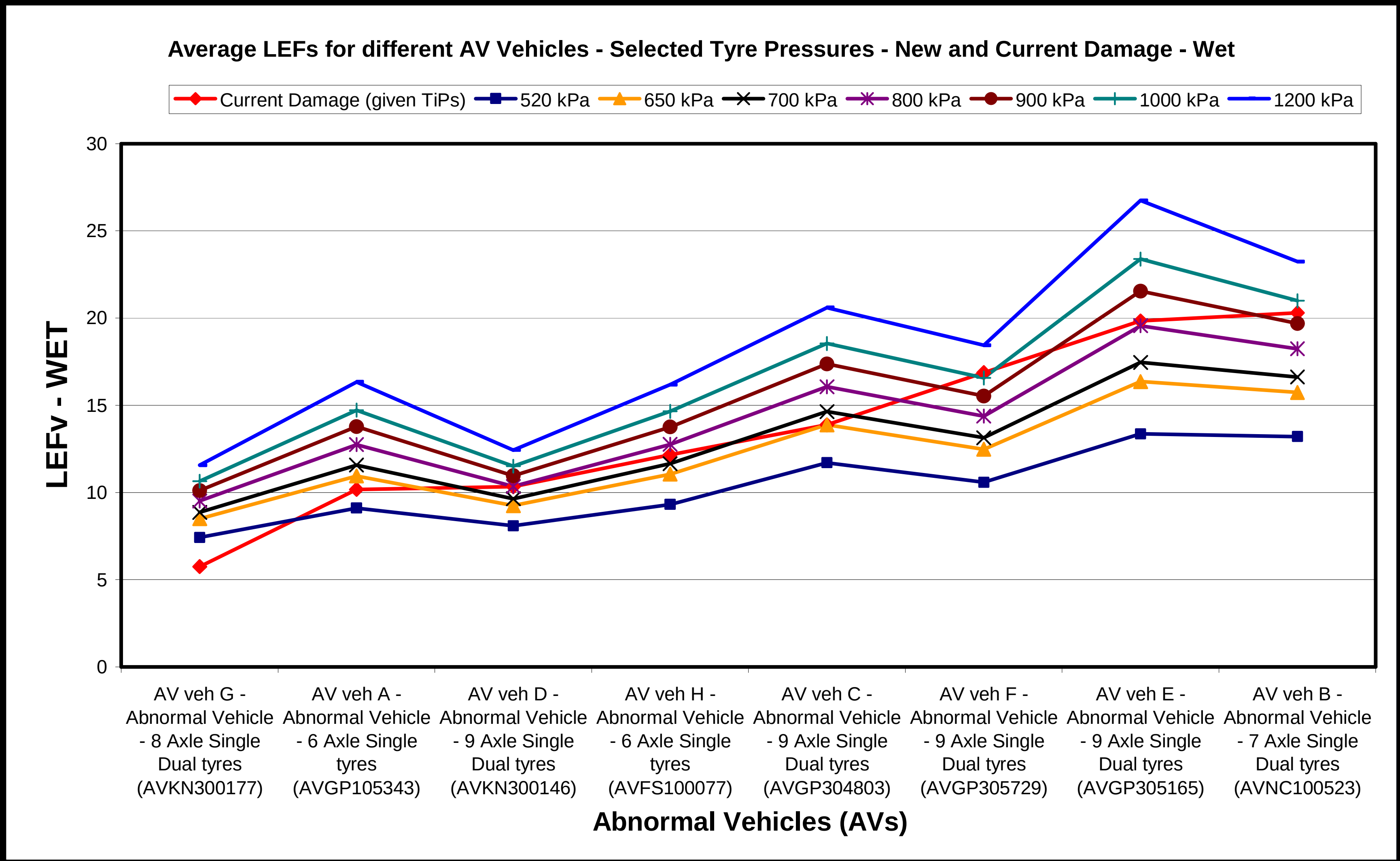
# Heavy Vehicles - Road Users:

| DESIGN LOCATION | Moisture Condition | VEHICLE ID | Current Damage (given TiPs) | 520 kPa | 650 kPa | 700 kPa | 800 kPa | 900 kPa | 1000 kPa | 1200 kPa |
|---|---|---|---|---|---|---|---|---|---|---|
| Outside | WET | AV veh G - Abnormal Vehicle - 8 Axle Single Dual tyres (AVKN300177) | 5.76 | 7.43 | 8.49 | 8.85 | 9.52 | 10.11 | 10.64 | 11.56 |
| Outside | WET | AV veh A - Abnormal Vehicle - 6 Axle Single tyres (AVGP105343) | 10.18 | 9.11 | 10.95 | 11.58 | 12.74 | 13.79 | 14.72 | 16.34 |
| Outside | WET | AV veh D - Abnormal Vehicle - 9 Axle Single Dual tyres (AVKN300146) | 10.34 | 8.09 | 9.25 | 9.64 | 10.35 | 10.97 | 11.51 | 12.43 |
| Outside | WET | AV veh H - Abnormal Vehicle - 6 Axle Single tyres (AVFS100077) | 12.16 | 9.32 | 11.06 | 11.66 | 12.77 | 13.76 | 14.65 | 16.19 |
| Outside | WET | AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803) | 13.88 | 11.70 | 13.88 | 14.64 | 16.07 | 17.36 | 18.54 | 20.60 |
| Outside | WET | AV veh F - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305729) | 16.87 | 10.59 | 12.47 | 13.14 | 14.39 | 15.53 | 16.58 | 18.44 |
| Outside | WET | AV veh E - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305165) | 19.84 | 13.36 | 16.37 | 17.47 | 19.57 | 21.54 | 23.39 | 26.73 |
| Outside | WET | AV veh B - Abnormal Vehicle - 7 Axle Single Dual tyres (AVNC100523) | 20.3 | 13.20 | 15.74 | 16.62 | 18.24 | 19.70 | 21.00 | 23.25 |

# Heavy Vehicles - Road Users:

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# Summary and Conclusions - 1

1 **EQUIVALENT PAVEMENT RESPONSE (EPR)- EQUIVALENT PAVEMENT DAMAGE (EPD):**
2 PRINCIPLES OF THE NEW "EPR-EPD" METHOD **– FULL MECHANISTIC;**
3 USE OF ESWL (or ESWM) - **NOT RECOMMENDED;**
4 PAVEMENT TYPES – **STRONG HEAVY to WEAK LIGHT;**
5 **ELEVEN - MOBILE CRANES;**
6 **EIGHT - ABNORMAL VEHICLES (AVs);**
7 **SPECIAL SOFTWARE (CALCULATION OF ROAD DAMAGE - LEFs)**
8 TYRE INFLATION PRESSURES (i.e. CONTACT STRESS) **- 520 to 1 200 kPa;**
9 **PROPOSED FORMULATIONS - ROAD DAMAGE:**
10 Legal Damage (LDv);
11 Total Damage (TDv) (= Load Equivalency Factor (LEFv) of Vehicle);
12 Total Additional Damage (TADv);
11 **MASS FEE AND PERMIT FEE FOR ROAD DAMAGE ONLY**

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# Summary and Conclusions - 2

LEF RESULTS: MOBILE CRANES& ABNORMAL VEHICLES:

Mobile Cranes - Current damage LEFs: 0.11 to 113;

- LEF - DRY: 0.5 to 382;
- LEF – WET: 7.0 to 382;

AVs - Current damage LEFs: 5.8 to 20.3;

- LEF - DRY: 1.3 to 41.2;
- LEF – WET: 7.6 to 41.2;

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# Summary and Conclusions - 3

EFFECT OF TYRE INFLATION PRESSURES (TiPs) ON LEFs:

- 520 kPa;
- 650 kPa;
- 700 kPa;
- 800 kPa;
- 900 kPa and
- 1 200 kPa;



 

# Summary and Conclusions - 4

## RESULTS: EFFECT OF TYRE INFLATION PRESSURES (TiPs) ON LEFs:

- Mobile Cranes - Current damage LEFs: 0.11 to 113;
  LEF - DRY: 3.59 to 455.32;
  LEF – WET: 5.24 to 461.88;

- AVs - Current damage LEFs: 5.8 to 20.3;

  LEF - DRY: 5.17 to 22.29;
  LEF – WET: 7.43 to 26.73;

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# Major Conclusions (1):

- A new methodology based on the principle of full mechanistic road pavement analysis for each Mobile Crane and each AV considered in this study results in a variation of Load Equivalency Factors (LEFs) to be effectively quantified.
- Above was demonstrated over a range of nine different pavement types, two pavement conditions and at different Tyre Inflation Pressures (TiPs);
- In general, the new LEFs compare favourably with those calculated with the existing ESWL method (i.e. current method) in terms of rating the different vehicles in terms of their road damage potential;
- The new method allows for different pavements and its condition to be modelled effectively for the typical abnormal vehicles (including Mobile Cranes) found in South Africa under static loading conditions only;

# Major Conclusions (2):

- The study show that relatively higher LEFs were determined for the weaker pavements, and also those analysed in the relatively WET pavement condition;
- The LEFs determined for the stronger pavements were found to be lower compared with the current ESWL method for both relatively dry and relatively wet pavement moisture conditions, especially for the Mobile Cranes;
- Tyre Inflation Pressure (TiPs) plays a major role in the estimation of LEFs, and hence road pavement damage. The higher the TiP, the higher the LEF, and associated road pavement damage for all pavement analysed.



 

# Major Conclusions (3):

- The new system of analysis provides for a more rational methodology for the estimation of road pavement damage, than perhaps given by the existing methodology based on ESWL, as each tyre load (hence axle load, and hence total load) is directly considered at the given TiP.
- *Note:  In this study the mechanistic analysis was done under static (or stationary) loading conditions. The "dynamic" loading (or "moving" or "cyclic" loading) …*

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# Major Recommendations (1):

- The newly proposed methodology for the determination of LEFs be discussed in detail with the relevant committee members concerned with draft TRH 11, including Officials from Road Authorities;
- The newly determined methodology be incorporated/implemented into TRH 11 over time, starting as soon as practical possible;
- A more wider definition of the Mobile Cranes and AVs be drawn up in terms of tyre load, tyre inflation pressures and axle configuration for further analysis;
- A simpler procedure for the determination of new LEFs for AVs and Mobile Cranes on a wider scale than is perhaps covered in this summary report should be further investigated, including appropriate software as the delivery system;

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# Major Recommendations (2):

- A methodology should be developed for the implementation of the findings of this preliminary study for the future review of TRH 11 (2000), and
- The foregoing to be implemented through a Geographical Information System (GIS) of road pavement types,… appropriate road damage (and hence permit fees) could be determined for each section of road structure on that route, resulting in a fairer and more appropriate road damage cost recovery;
- Future studies to also investigate the use of “Dynamic Load Coefficients” (DLCs) or “Impact Factors” (IFs) under dynamic (or moving) loading in order to estimate road damage of moving vehicles.
- The output from this study to be used with care by industry and associated road authorities.

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# Thank You for listening…!

*[South Africa - Snow and some clouds - June 25, 2009]*

Thursday, June 25, 2009 - http://intraweb.csir.co.za/news/articles/2009/06/chilling.php