Structural analysis of HiMA pavements

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- **High modulus HMA in France:**
  - **EME (Enrobé à Module Elevé) since early 1980's**

  French standard NF P 98 140

  - **BBME (Béton Bitumineux à Module Elevé) since early 1990's**

  French standard NF P 98 141

- **Developed by:**
  - **French Administration (LCPC)**
  - **Bitumen producers (Total, Elf,...)**
  - **Roads Contractors (Via France...)**

High Modulus Asphalt (HiMAs)

French development Enrobe' `a **M**odule **E'**leve' (**EME)**

HiMAs or EMEs have:

- Increased stiffness moduli
- Improved fatigue resistance
- Improved resistance to deformation
- No polymer additions! Can therefore be recycled!

HiMAs are produced from:

- Hard bitumen binders
- Special refinery processes with specific crudes
- Higher binder quality

French Specifications

	EME 1	EME 2	GB 2
Granularity and average thickness of lifts	0/10 6 to 10 cm 0/14 7 to 12 cm 0/20 10 to 15 cm	0/10 6 to 10 cm 0/14 7 to12 cm 0/20 10 to 15 cm	0/14 8 to 12 cm 0/20 10 to 15 cm
Minimum richness factor for asphalt content (*K*)	≥2.5	≥3.4	≥2.5
Binder content for 0/14 grading	≥4.2 pph	≥5.7 pph	≥4.2 pph
Duriez test (*r*/*R*)	≥0.70	≥0.75	≥0.65
Wheel-tracking rutting test (60°C, 30,000 cycles)	≤7.5 %	≤7.5 %	≤7.5 %
Fatigue test ε_6 (10^{-6}) (15°C, 25 Hz)	≥100	≥130	≥80
Max voids content (%)	≤10	≤6	≤11

NOTE: EME = enrobé à module élevé, GB = grave-bitume.

Table 3: Characteristics of the special binder (Didier et al, 2000)

Characteristics	**Test Method**	**Values**
Penetration at 25^{0}C (1/10mm)	NFT 66-004	6
Ring and Ball softening point (^{o}C)	NFT 66-008	87.0
Pfeifer Penetration Index	RLB-1-1964	+1.0
LCPC Penetration Index	TOTAL 763	+1.6
Kinematic viscosity at 170^{o}C (mm^2/s)	ASTM D2170	592

Table 4: Pavement profile tested under the circular APT of LCPC (Didier, 2000)

Materials	**Thickness (mm)**	**Modulus (MPa)**
Sand asphalt mix	20	4 700
Granular material	300	200
Cement-bound sand	100	500
Soil	4000	21

HiMA effective elastic moduli range from 8000MPa to 25 000MPa

Used the same structural analysis methodology as for the REVISION OF TRH 11 (1999-2000): RECOVERY OF ROAD DAMAGE

Not based on the traditional Equivalent Single Wheel Load (or Mass) ESWL (or ESWM)

Nor on the well known 4th power law for relative pavement damage.

The current SAMDM methodology is used to estimate the Load Equivalency Factors (LEFs) of each vehicle, based on the critical pavement layer life approach.

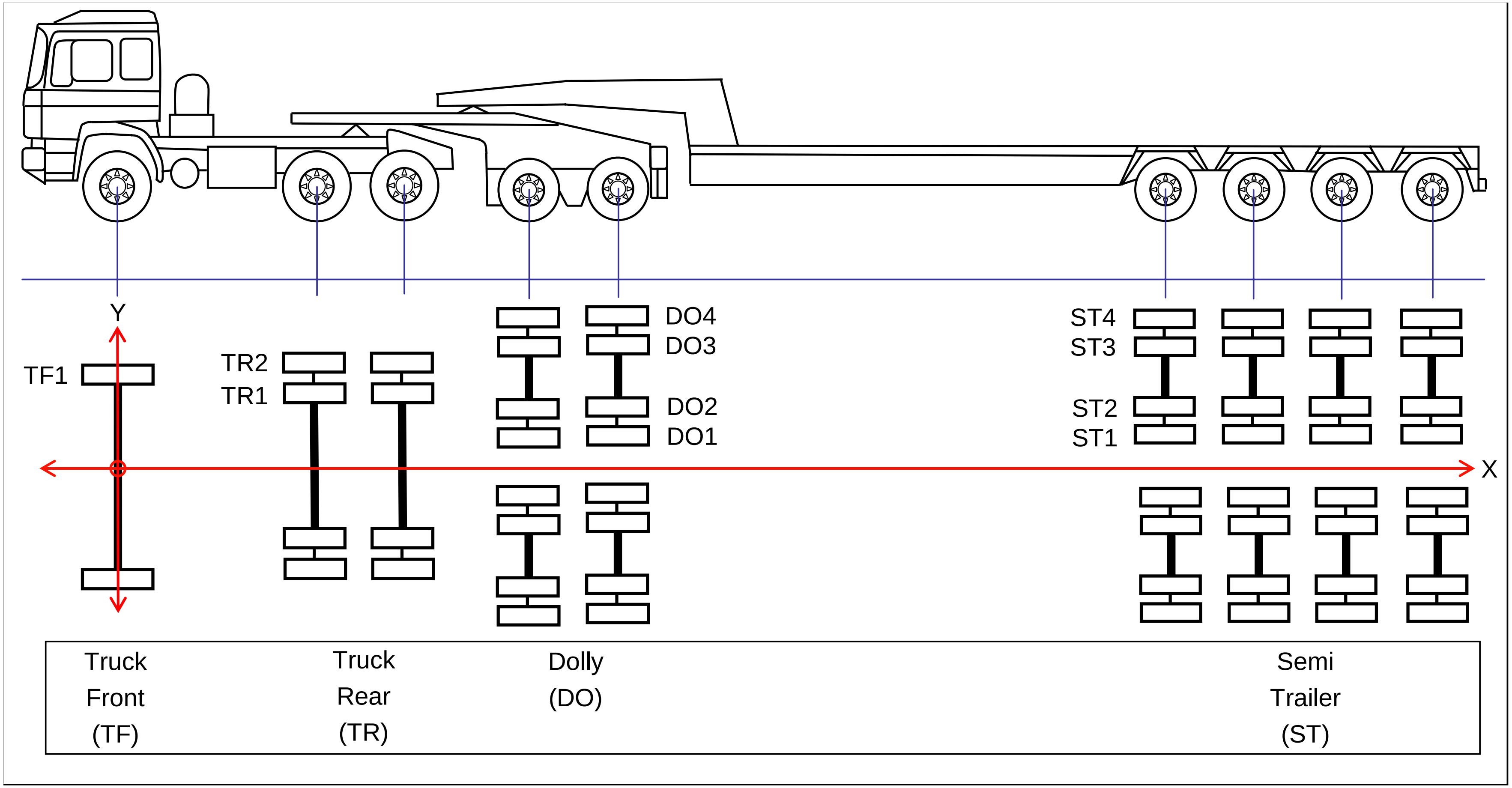
Standard and Legal Axle data used

STANDARD AND LEGAL AXLES:	Standard Deviation (kN)	Total Load (kN)	Number of Tyres	Standard De (kPa)
Standard Axle (Std)	0.00	80.00	4	0.00
Legal Axle (Lg)	0.00	88.00	4	0.00

Table 1. Summary of the eight Abnormal Vehicles (AVs) (sorted on Total Load)

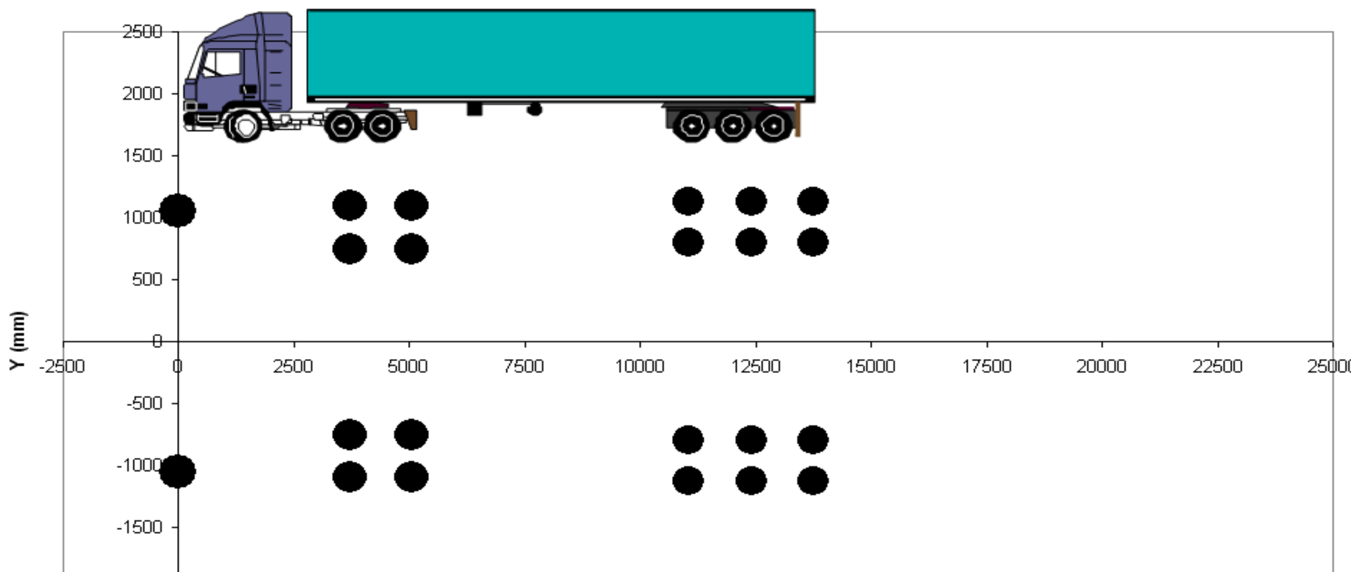
ABNORMAL VEHICLES (SORTED ON TOTAL LOAD):	Standard Deviation (kN)	Total Load (kN)	Number of Tyre	Standard Deviation (kPa)
AV veh H - Abnormal Vehicle - 6 Axle Single tyres (AVFS100077)	4.76	559.00	22	86.78
AV veh A - Abnormal Vehicle - 6 Axle Single tyres (AVGP105343)	1.80	643.00	22	29.20
AV veh B - Abnormal Vehicle - 7 Axle Single Dual tyres (AVNC100523)	2.60	711.50	26	14.88
AV veh G - Abnormal Vehicle - 8 Axle Single Dual tyres (AVKN300177)	4.47	878.40	50	209.46
AV veh D - Abnormal Vehicle - 9 Axle Single Dual tyres (AVKN300146)	5.34	962.00	58	4.29
AV veh F - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305729)	5.39	1130.60	58	162.10
AV veh C - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP304803)	5.58	1211.20	58	80.22
AV veh E - Abnormal Vehicle - 9 Axle Single Dual tyres (AVGP305165)	6.62	1292.80	58	1.14

Axle Configurations of typical abnormal load combinations

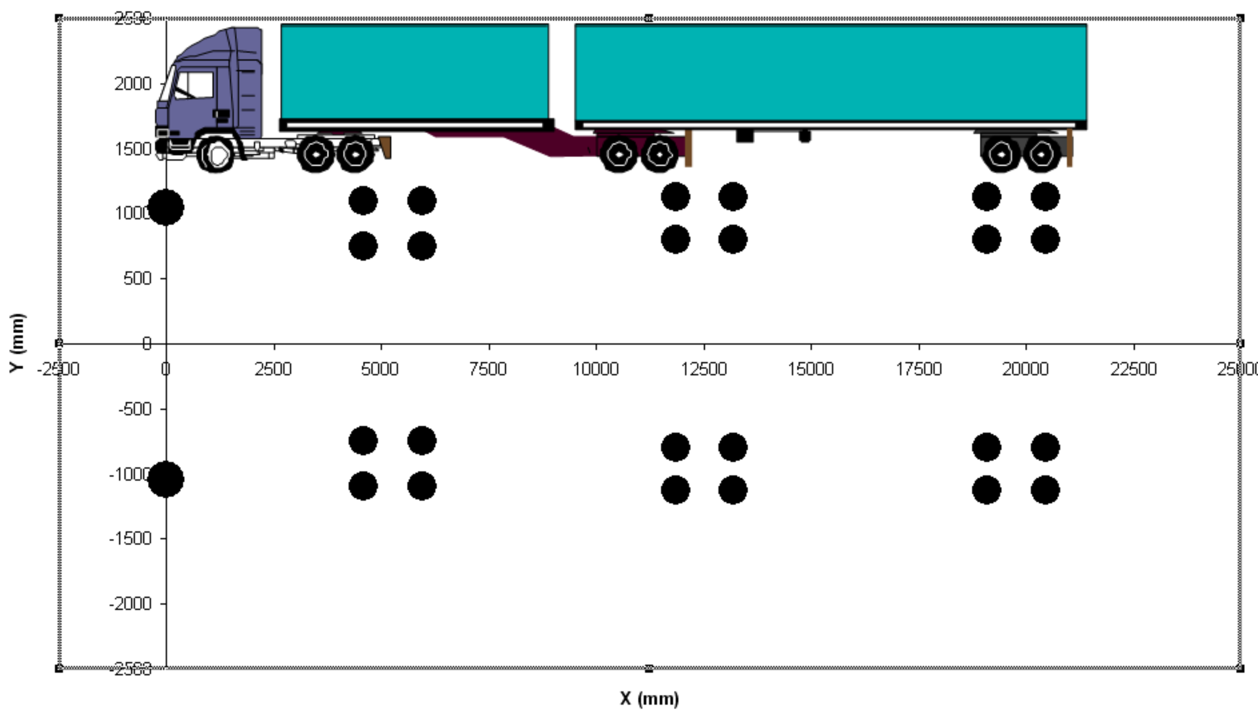


The analysis is based on a comparative analysis with abnormal vehicle damage to typical pavement structures

Load Positions: Articulated 6Ax veh A - 6 Axle Single Dual tyres - config 123



Load Positions: Interlink 7Ax veh A - 7 Axle Single Dual tyres - config 1222



REVISION OF TRH 11 (1999-2000): RECOVERY OF ROAD DAMAGE

-DISCUSSION DOCUMENT ON A PROVISIONAL BASIS FOR POSSIBLE NEW ESTIMATION OF MASS FEES

Authors: M De Beer
I Sallie
Y van Rensburg

Load Equivalency Factor (LEFv) of Vehicle) concept used

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

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.*

Used the pavement structures analysed in the REVISION OF TRH 11 (1999-2000): RECOVERY OF ROAD DAMAGE

Strong pavement structure

Light pavement structure

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
	-	-	-

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
	-	-	-	-

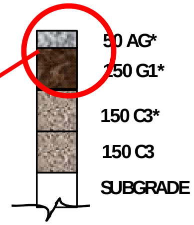
Pavement H: ES0.3

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)

Pavement A:

ES100



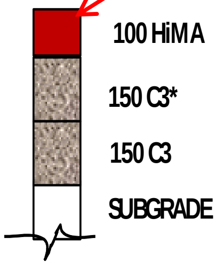
Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	2000	2000	1500
0.35	450	450	350
0.35	2000	2000	500
0.35	1500	550	250
0.35	180	180	180

Replaced the base and surfacing with a thinner HiMA layer

200mm base & surfacing replaced by 100mm HiMA

Pavement A:

ES100



Scenario 1

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	8000	5000	3000
0.35	2000	2000	500
0.35	1500	550	250
0.35	180	180	180

Scenario 2

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	15000	10000	5000
0.35	2000	2000	500
0.35	1500	550	250
0.35	180	180	180

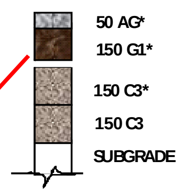
Scenario 3

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	20000	10000	5000
0.35	2000	2000	500
0.35	1500	550	250
0.35	180	180	180

Varied the effective elastic moduli based on range of values found in literature

Pavement B:

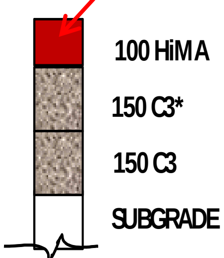
ES100



Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	2000	1800	1500
0.35	250	250	240
0.35	2000	1700	160
0.35	1500	120	110
0.35	90	90	90

Pavement B:

ES100



Scenario 1

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	8000	5000	3000
0.35	2000	1700	160
0.35	1500	120	110
0.35	90	90	90

Scenario 2

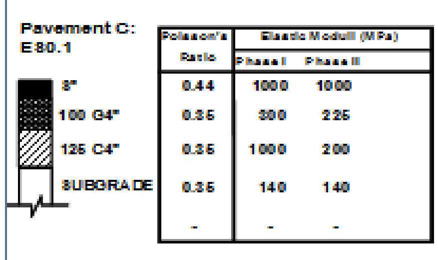
Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	15000	10000	5000
0.35	2000	1700	160
0.35	1500	120	110
0.35	90	90	90

Scenario 3

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	20000	10000	5000
0.35	2000	1700	160
0.35	1500	120	110
0.35	90	90	90

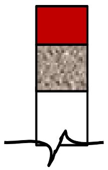
Pavement C:

ESO.1



Pavement C:
E80.1

Poisson's Ratio	Elastic Moduli (MPa)	
	Phase I	Phase II
0.44	1000	1000
0.35	300	225
0.35	1000	200
0.35	140	140
-	-	-



70 HiMA
125 C4*
SUBGRADE

Scenario 1

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	8000	5000
0.35	1000	200
0.35	140	140
-	-	-

Scenario 2

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	15000	10000
0.35	1000	200
0.35	140	140
-	-	-

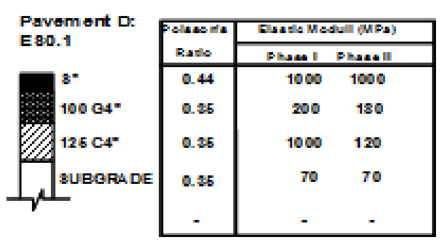
Scenario 3

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	20000	10000
0.35	1000	200
0.35	140	140
-	-	-

Thinner HiMA layer in place of base and surfacing layers

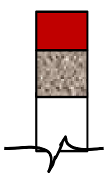
Pavement D:

ESO.1



Pavement D:
E80.1

Poisson's Ratio	Elastic Moduli (MPa)	
	Phase I	Phase II
0.44	1000	1000
0.35	200	180
0.35	1000	120
0.35	70	70
-	-	-



70 G1*
125 C4*
SUBGRADE

Scenario 1

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	8000	5000
0.35	1000	120
0.35	70	70
-	-	-

Scenario 2

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	15000	10000
0.35	1000	120
0.35	70	70
-	-	-

Scenario 3

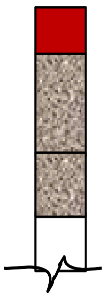
Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	20000	10000
0.35	1000	120
0.35	70	70
-	-	-

Pavement E:
ES30/ ES50

Pavement E:
ES30/ES50

40 AG*
120 BC*
450 C3*
200 G7*
SUBGRADE

Poisson's Ratio	Elastic Moduli (MPa)		
	Phase I	Phase II	Phase III
0.44	2500	2500	1000
0.44	3500	3500	1500
0.35	2200	1000	300
0.35	300	300	200
0.35	150	150	140



90 HiMA
450 C3*
200 G7*
SUBGRADE

Scenario 1

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	8000	5000	
0.35	2200	1000	300
0.35	300	300	200
0.35	150	150	140

Scenario 2

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	15000	10000	5000
0.35	2200	1000	300
0.35	300	300	200
0.35	150	150	140

Scenario 3

Poisson's Ratio	Elastic Moduli (Mpa)		
	Phase 1	Phase 2	Phase 3
0.44	20000	10000	5000
0.35	2200	1000	300
0.35	300	300	200
0.35	150	150	140

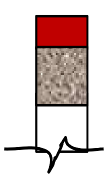
Thinner HiMA layer in place of base and surfacing layers

Pavement F:
ES30/ ES50

Pavement F:
ES1.0

S*
30 BC*
150 C4*
SUBGRADE

Poisson's Ratio	Elastic Moduli (MPa)	
	Phase I	Phase II
0.44	2000	1600
0.44	2000	1600
0.35	1000	300
0.35	140	140
-	-	-



50 HiMA
150 C4*
SUBGRADE

Scenario 1

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	8000	5000
0.35	1000	300
0.35	140	140
-	-	-

Scenario 2

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	15000	10000
0.35	1000	300
0.35	140	140
-	-	-

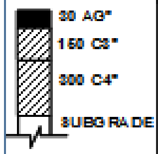
Scenario 3

Poisson's Ratio	Elastic Moduli (Mpa)	
	Phase 1	Phase 2
0.44	20000	10000
0.35	1000	300
0.35	140	140
-	-	-

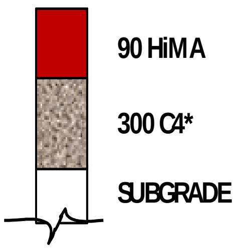
Pavement G:

ES10

Pavement G:
ES10



Poisson's Ratio	Elastic Moduli (MPa)		
	Phase I	Phase II	Phase III
0.44	2400	2000	1600
0.35	2000	1800	250
0.35	1000	300	100
0.35	180	140	100
-	-	-	-



Scenario 1

Poisson's	Elastic Moduli (Mpa)		
Ratio	Phase 1	Phase 2	Phase 3
0.44	8000	5000	3000
0.35	1000	300	100
0.35	180	140	100
-	-	-	-

Scenario 2

Poisson's	Elastic Moduli (Mpa)		
Ratio	Phase 1	Phase 2	Phase 3
0.44	15000	10000	5000
0.35	1000	300	100
0.35	180	140	100
-	-	-	-

Scenario 3

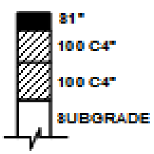
Poisson's	Elastic Moduli (Mpa)		
Ratio	Phase 1	Phase 2	Phase 3
0.44	20000	10000	5000
0.35	1000	300	100
0.35	180	140	100
-	-	-	-

Pavement H:

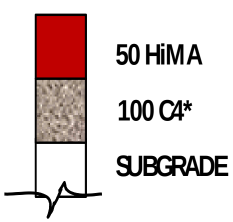
ES0.3

Thinner HiMA layer in place of base and surfacing layers

Pavement H:
ES0.3



Poisson's Ratio	Elastic Moduli (MPa)		
	Phase I	Phase II	Phase III
0.44	2000	1000	200
0.35	2000	1500	100
0.35	1000	300	100
0.35	140	140	100
-	-	-	-



Scenario 1

Poisson's	Elastic Moduli (Mpa)		
Ratio	Phase 1	Phase 2	Phase 3
0.44	8000	5000	3000
0.35	1000	300	100
0.35	140	140	100
-	-	-	-

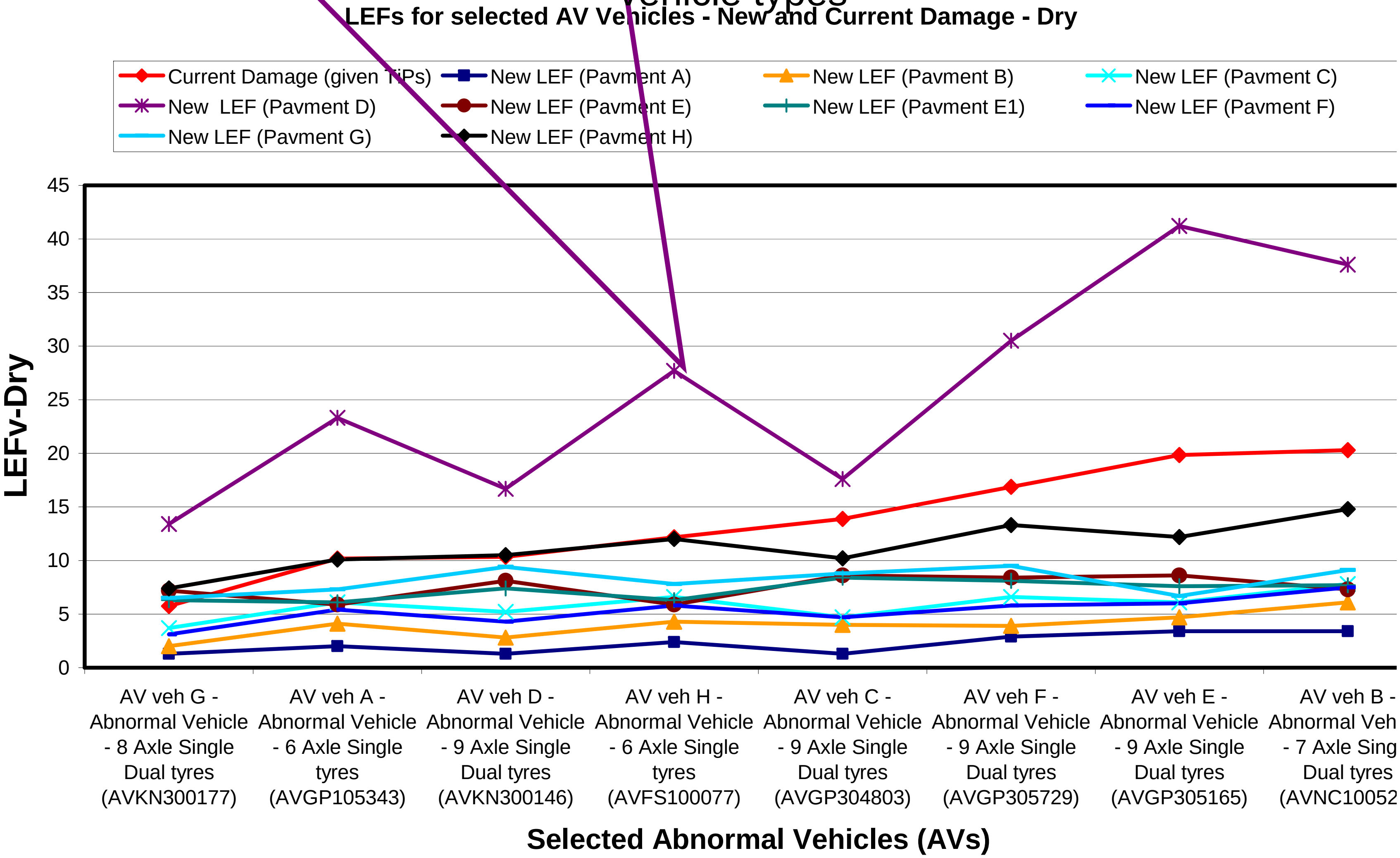
Scenario 2

Poisson's	Elastic Moduli (Mpa)		
Ratio	Phase 1	Phase 2	Phase 3
0.44	15000	10000	5000
0.35	1000	300	100
0.35	140	140	100
-	-	-	-

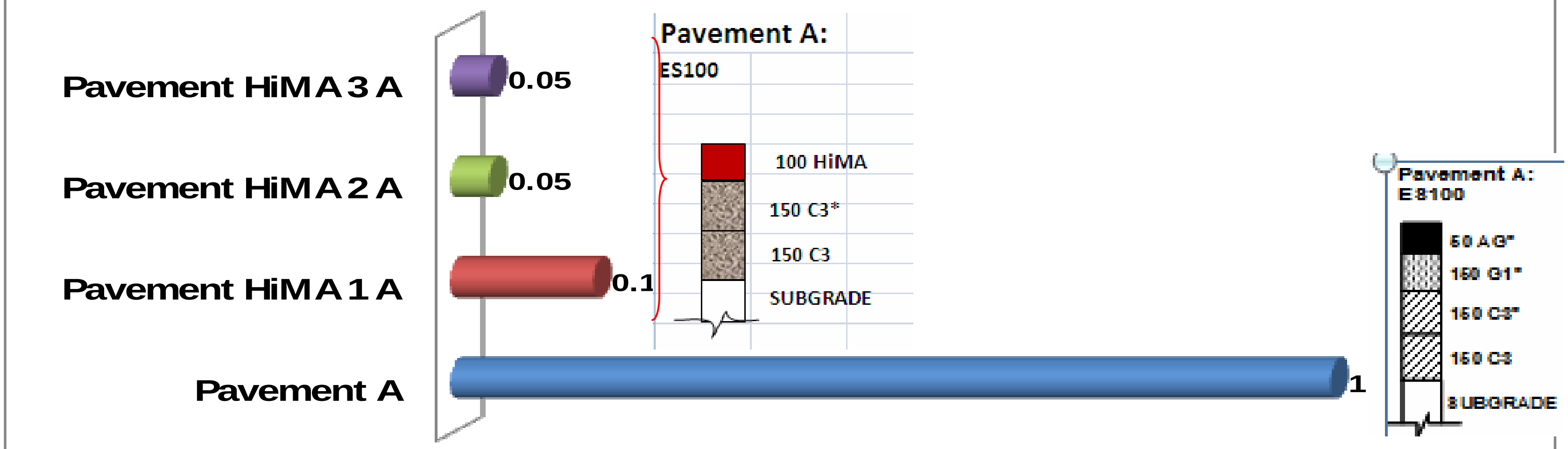
Scenario 3

Poisson's	Elastic Moduli (Mpa)		
Ratio	Phase 1	Phase 2	Phase 3
0.44	20000	10000	5000
0.35	1000	300	100
0.35	140	140	100
-	-	-	-

In the TRH11 revision the light pavement type D consistently showed up to be very sensitive to overloading for all abnormal vehicle types

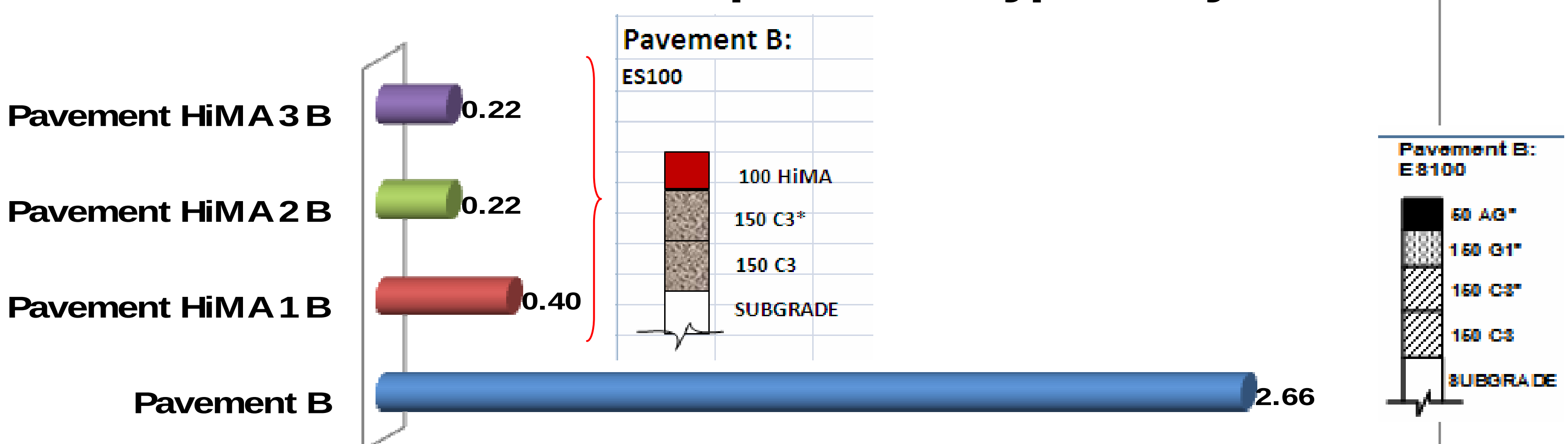


Six axle vehicle LEFv for pavement type A Dry

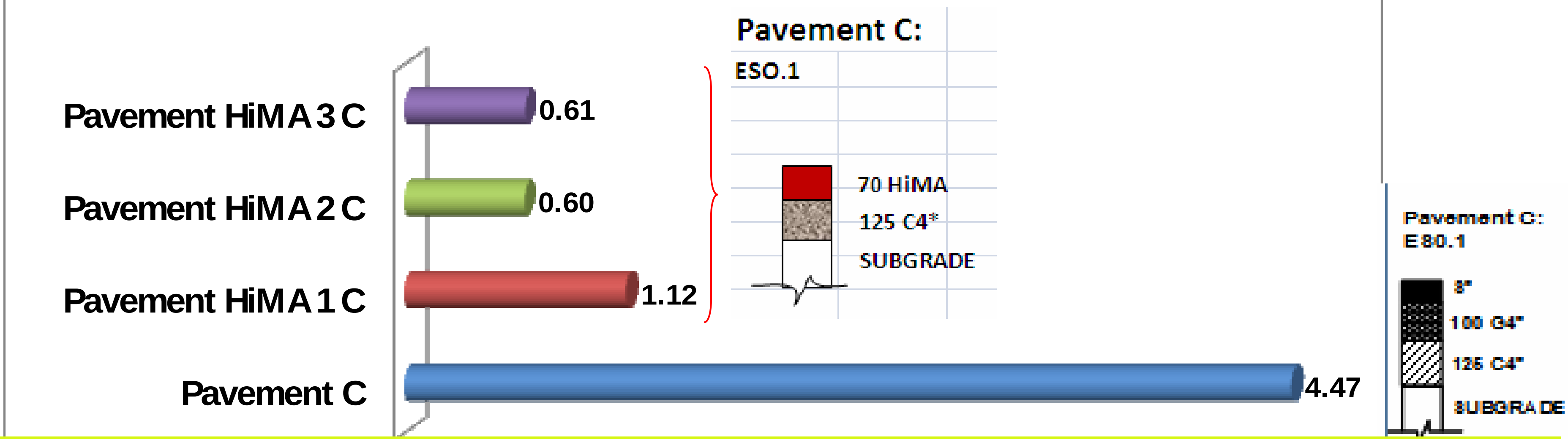


The strong pavement types showed reduced LEF for the HiMA base replacement

Six axle vehicle LEFv for pavement type B Dry

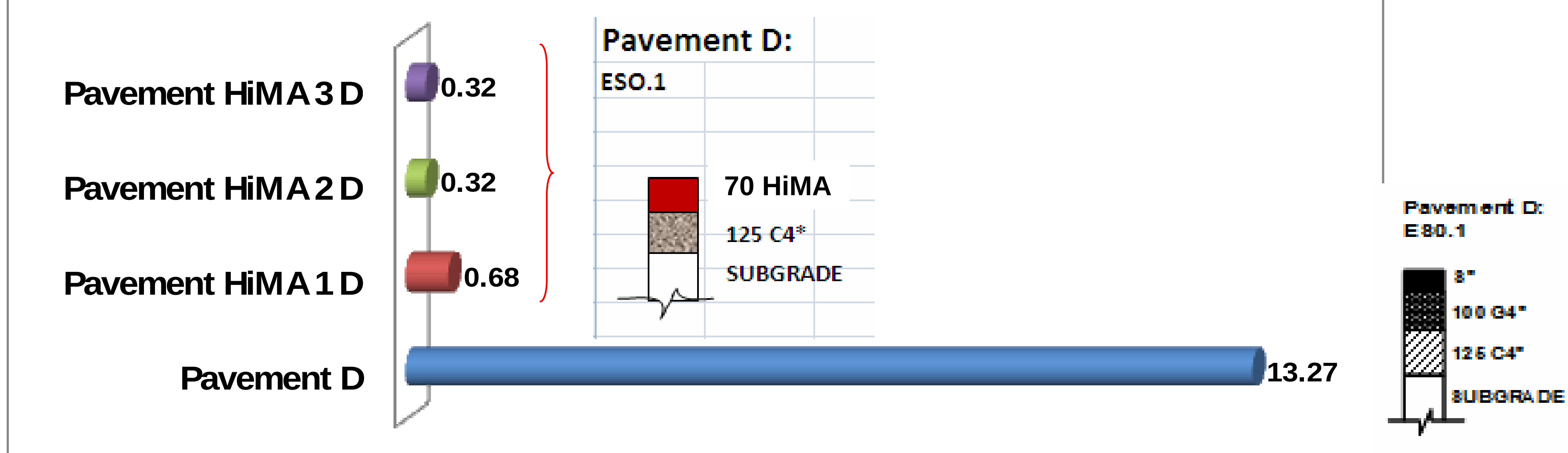


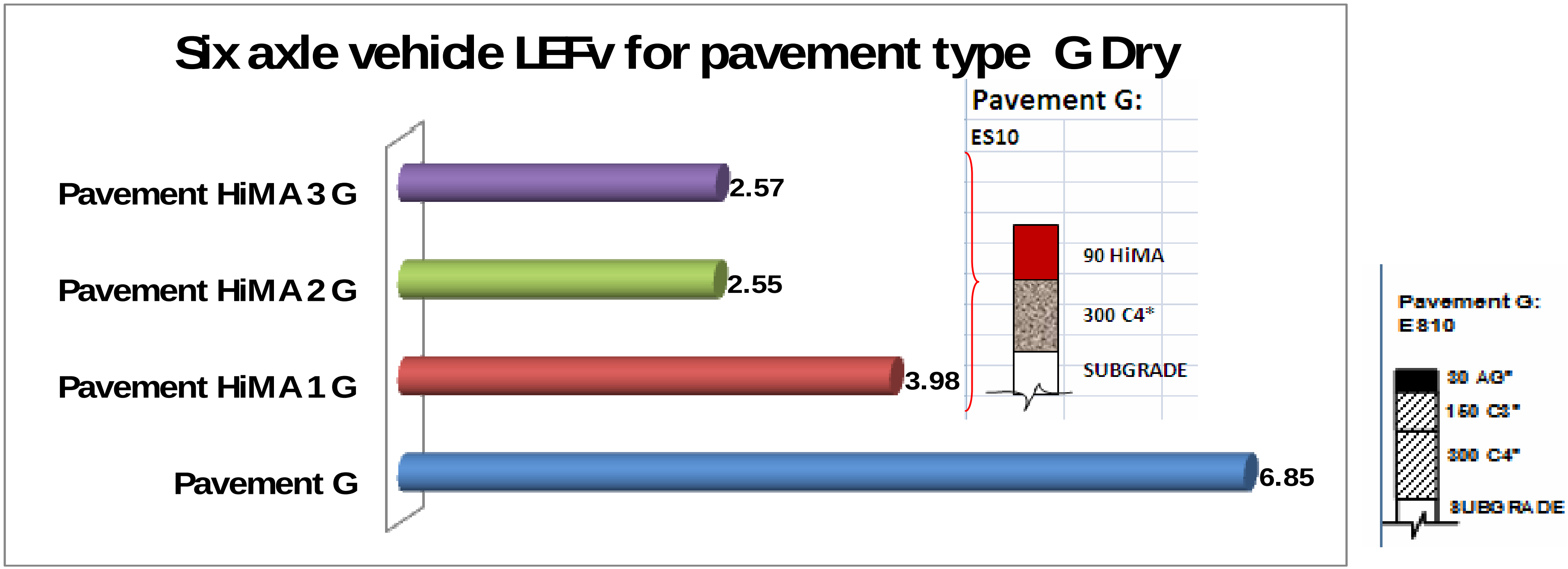
Six axle vehicle LEFv for pavement type C Dry

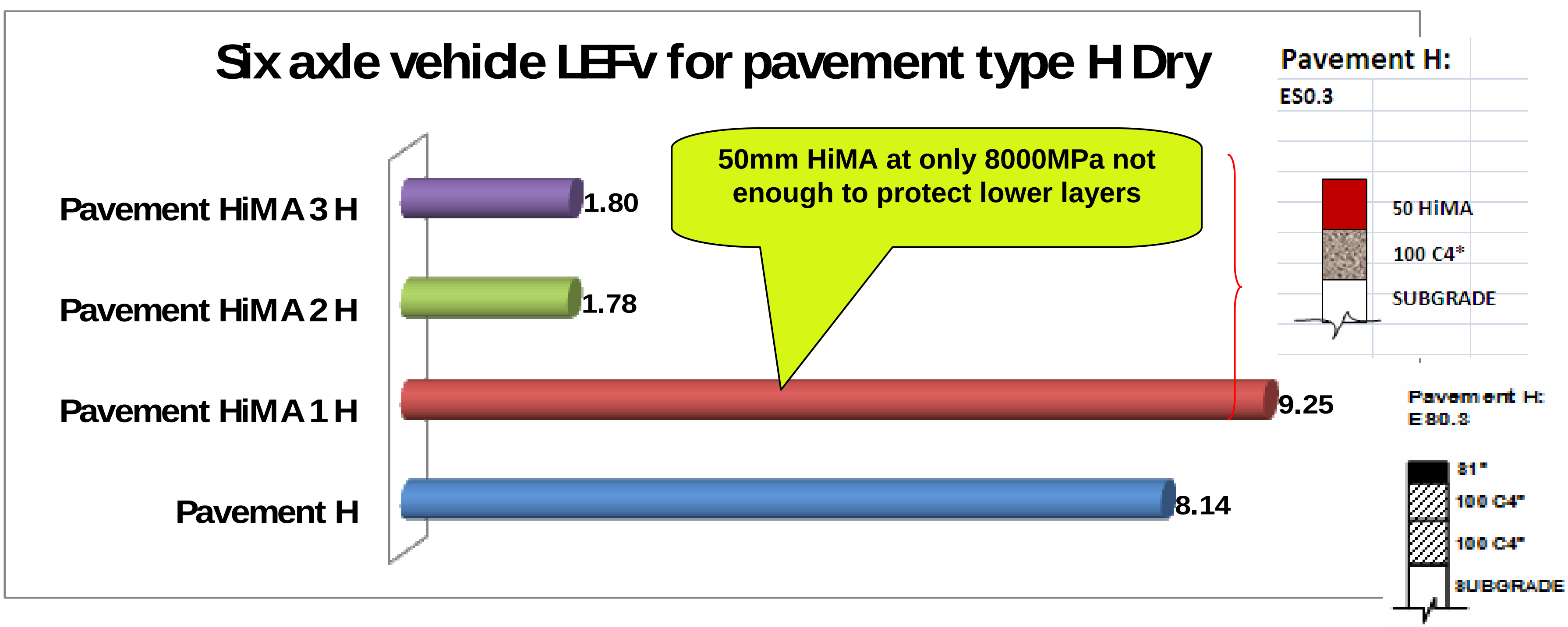


Reduced LEF for HiMA replacement: Therefore better protection of pavement

Six axle vehicle LEFv for pavement type D Dry

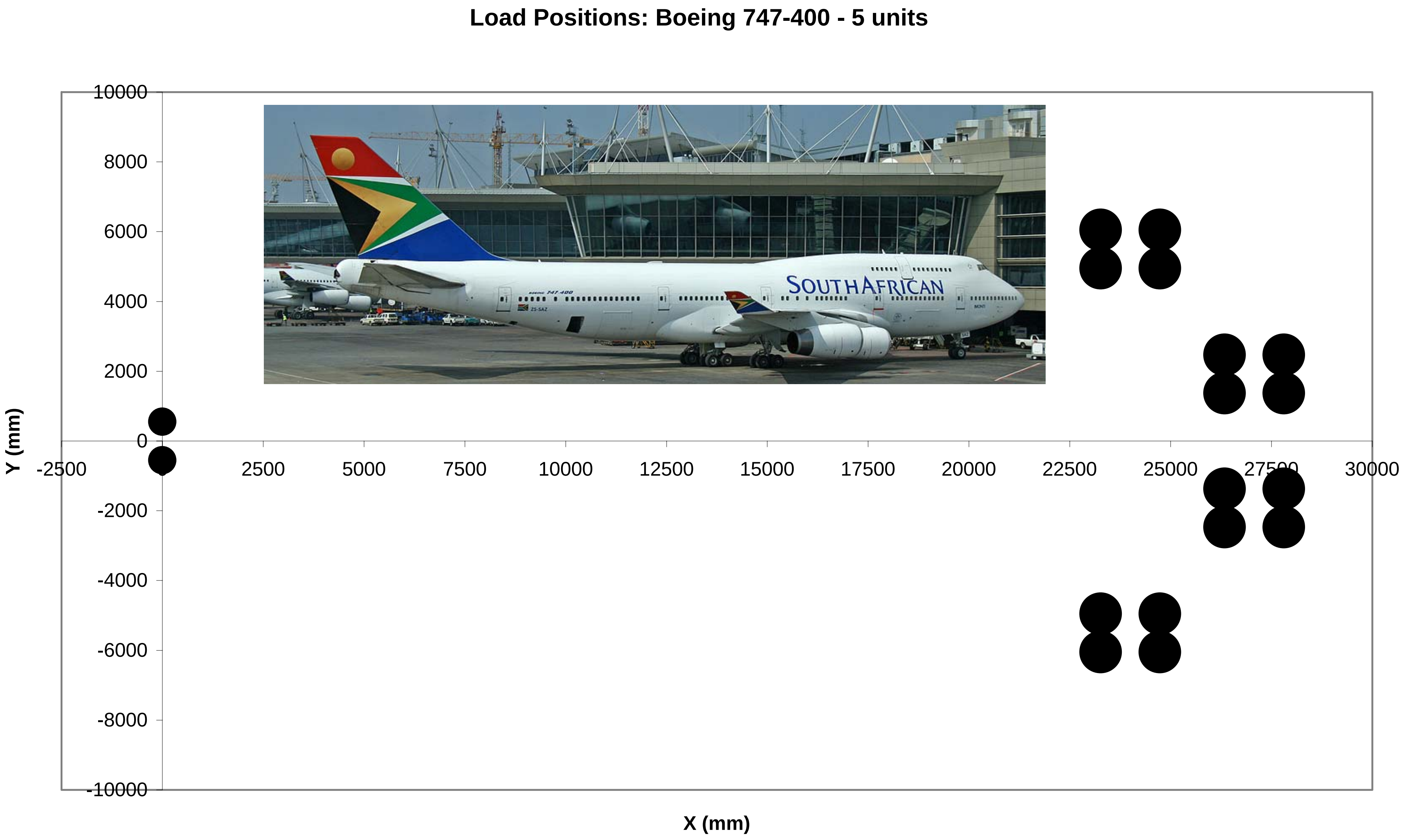



Six axle vehicle LEFv for pavement type G Dry
Pavement HiMA 3 G
Pavement HiMA 2 G
Pavement HiMA 1 G
Pavement G
2.57
2.55
3.98
6.85
Pavement G:
ES10
90 HiMA
300 C4*
SUBGRADE

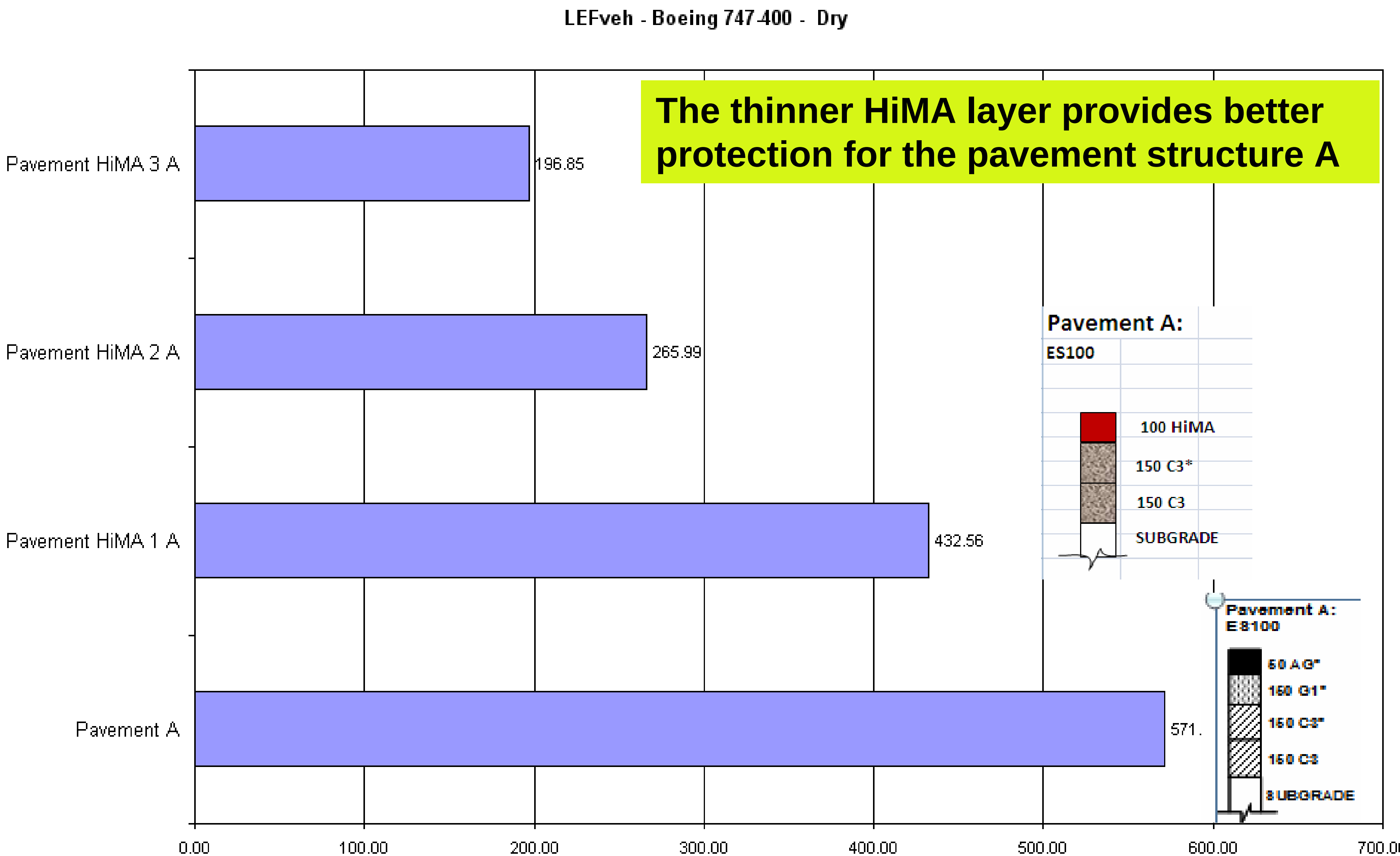

Six axle vehicle LEFv for pavement type H Dry
Pavement HiMA 3 H
Pavement HiMA 2 H
Pavement HiMA 1 H
Pavement H
1.80
1.78
9.25
8.14
50mm HiMA at only 8000MPa not enough to protect lower layers
Pavement H:
ES0.3
50 HiMA
100 C4*
SUBGRADE

HiMA was developed partially for the strengthening of taxiways and runways in preparation of the Airbus A 380 arrival

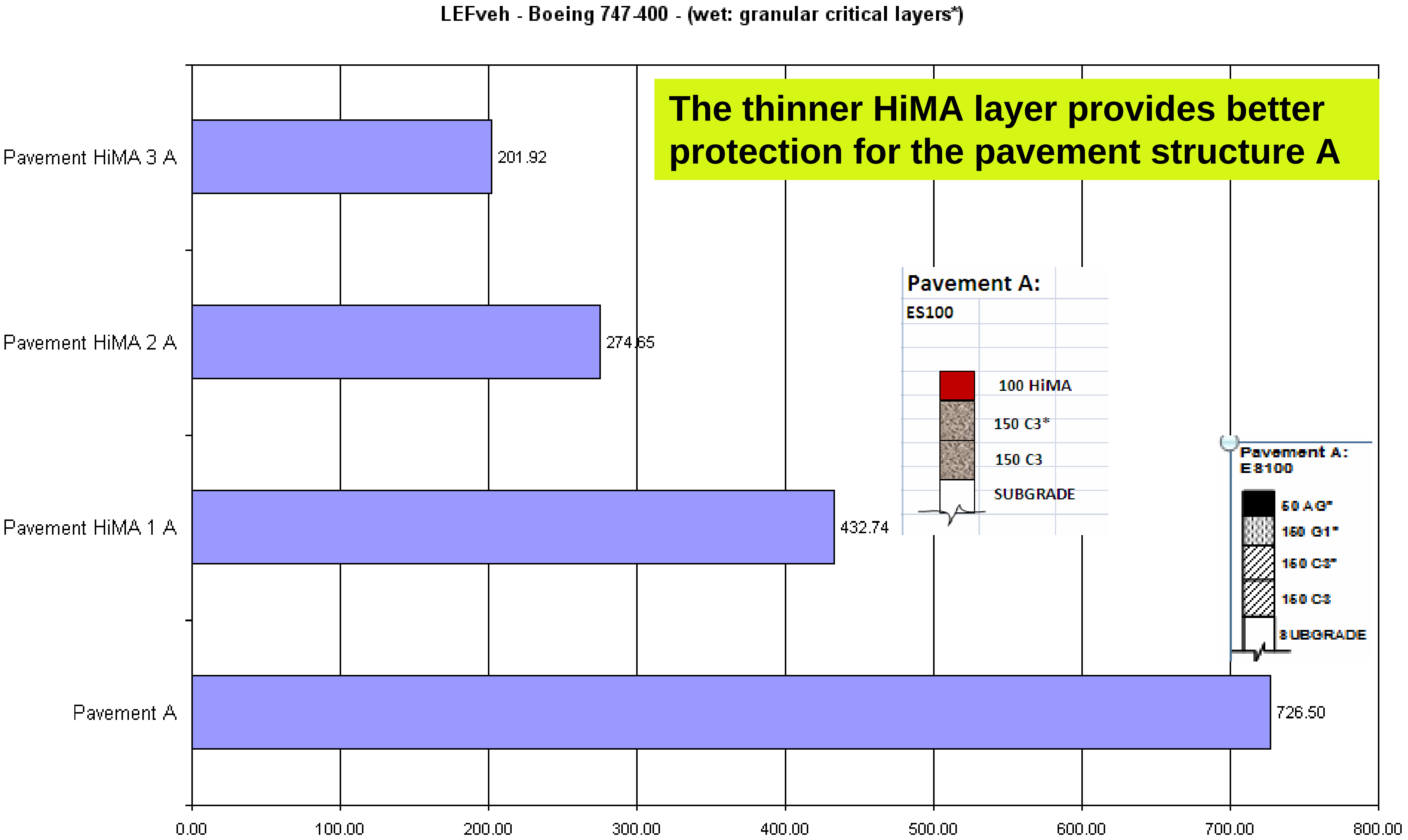
95% of this macro load is carried by the unique and large fuselage triple bogeys and wing double bogeys



Load Positions: Boeing 747-400 - 5 units
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
Y (mm)
-2500
2500
5000
7500
10000
12500
15000
17500
20000
22500
25000
27500
30000
X (mm)
SOUTHAFRICAN

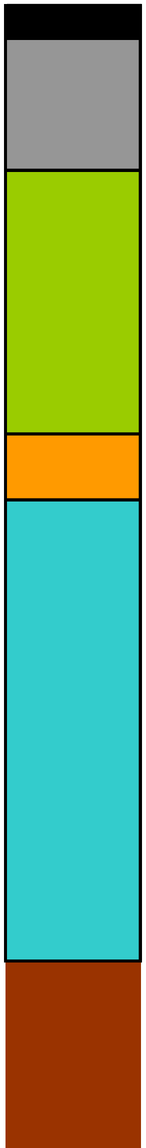


LEFveh - Boeing 747-400 - Dry
The thinner HiMA layer provides better protection for the pavement structure A
Pavement HiMA 3 A
196.85
Pavement HiMA 2 A
265.99
Pavement HiMA 1 A
432.56
Pavement A
571.
Pavement A:
ES100
100 HiMA
150 C3*
150 C3
SUBGRADE
Pavement A:
ES100
50 AG*
150 G1*
150 C3*
150 C3
SUBGRADE
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00



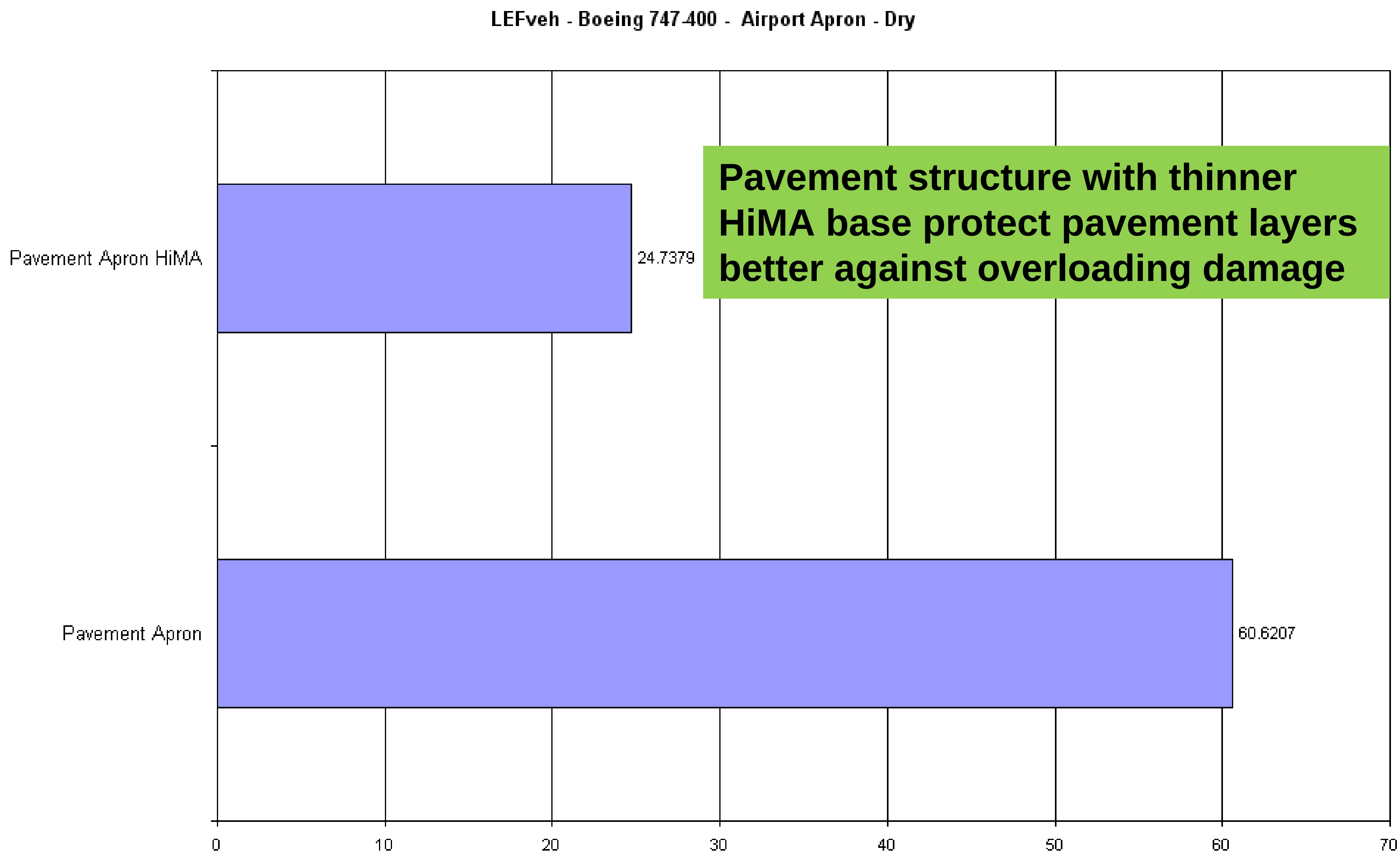
LEFveh - Boeing 747-400 - (wet: granular critical layers*)
The thinner HiMA layer provides better protection for the pavement structure A
Pavement HiMA 3 A
201.92
Pavement HiMA 2 A
274.65
Pavement HiMA 1 A
432.74
Pavement A
726.50
Pavement A:
ES100
100 HiMA
150 C3*
150 C3
SUBGRADE
Pavement A:
ES100
50 AG*
150 G1*
150 C3*
150 C3
SUBGRADE
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00

Apron std design flexible



E-Moduli (Mpa)

	Phase I	Phase II	Phase II
60 AC	3000	2000	1500
150 BTB	6000	4000	2000
250 C2	4000	1500	400
150G5	250	180	120
500Rockfill	450	300	250
Insitu subgrade	80	70	60


LEFveh - Boeing 747-400 - Airport Apron - Dry
Pavement Apron HiMA
24.7379
Pavement Apron
60.6207
0
10
20
30
40
50
60
70
Pavement structure with thinner HiMA base protect pavement layers better against overloading damage

Conclusions

HiMA has higher effective elastic moduli than normal asphalt

Ranging from approximately 8GPa to 25GPa

HiMA layers can reduce pavement base thicknesses by approximately 30% of normal thicknesses

In comparative analysis with abnormal vehicles HiMA replacement protects the pavement better against over loading for most pavement types

HiMA base replacements also protect relatively strong pavements better against Aircraft loading (Boeing 747-400 as design aircraft)

Conclusions (continued)

HiMA base layers don't just offer thinner BTB layers, but offers sustainable Life Long or perpetual pavements as per the CALTRANS HVS studies (hard on top softer longer life at the bottom)

The Warm Mix Asphalt technologies offers exciting opportunities for the improved constructability of HiMA in SA (Lower mix temperatures, extended paving periods at lower temperatures)