SPENS Final seminar
27 – 28 August 2009

Laboratory and field implementation of high modulus asphalt concrete

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Task 4.2 leader

Ljubljana, Slovenija

SPENS – work packages

WP4. Road upgrading methods - Marjan Tušar

- 4.2 Material Recommendations and Performance-based Requirements for High Modulus Asphalt Mixtures and Flexible Pavement Design

IBDiM	**POLAND**
ZAG	SLOVENIA
VTI	SWEDEN
TECER	ESTONIA
IGH	CROATIA
IP	SERBIA
CRBL	BULGARIA

Outline of presentation

- Objectives of WP4.2
- High modulus asphalt concrete (HMAC) in Poland
- Results of laboratory tests
- ALT on test fields in Poland (HVS)
- Conclusions

Objectives of WP 4.2

- To develope concept of high modulus asphalt concrete for implementation in Central and Eastern European countries
- Laboratory tests
- Field validation
- Preparation of general requirements for HMAC for different countries taking into account climate conditions, materials and available test methods

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History

- France – EME + BBTM
- Research works in IBDiM, 1999-2006
- First trial section 2001
- Poland – BAWMS (HMAC) Zeszyt 70 „Execution principles for asphalt pavement with better resistance to rutting and fatigue” ZW-WMS-2006”
- First edition 2002
- Second edition 2007
- SPENS 2006-2009
- National document for EN 13108 (2009)

HMAC - general rules

- Designed for binder course and base course
- Mix design only according to fundamental approach (EN 13108-1)
- Improved properties
  - High stiffness
  - Resistance to rutting
  - High resistance to fatigue

HMAC – general rules (2)

Grading 0/11 - 0/16 mm
Grading as for AC wearing course
Binder content around 5,0 % m/m
PMB or harder bitumen

Fatigue resistance

Rutting resistance

Stiffness

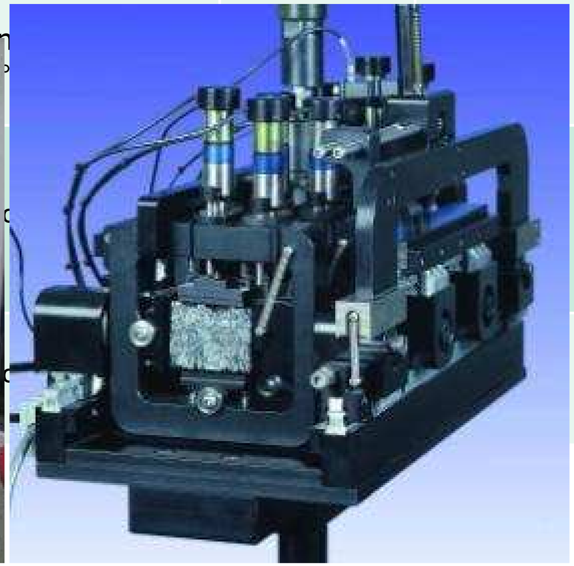
Requirements and materials

Material	Traffic category	
	KR3-6	
Upper sieve size D, mm	11	16
Binder	20/30, 15/25, 10/20 PMB 10/40-65 PMB 10/40-75	
Aggregates	As for AC base course	

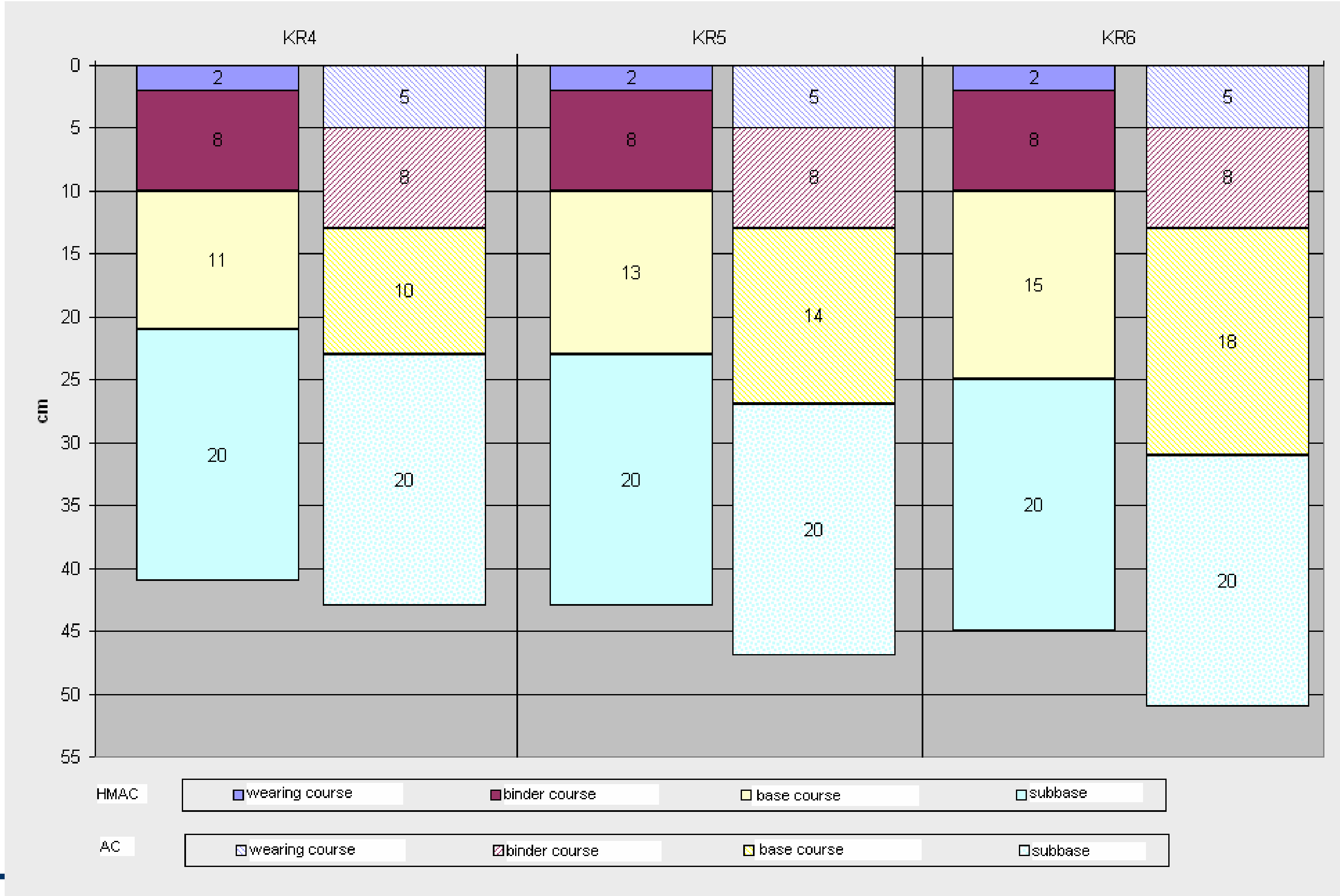
Właściwość	AC WMS 11		AC WMS 16	
Sieve size#, mm Passing:	Upper	Lower	Upper	lower
22,4			100	
16	100		90	100
11,2	90	100	70	85
8	70	85		
2	40	50	35	45
0,125	7	17	7	17
0,063	5	9	5	9
Minimum binder content, B_{min}	$B_{min4,8}$		$B_{min4,8}$	

HMAC - requirements

Properties	Compaction (PN-EN 13108-20)	Method and test conditions	KR3-6	
			AC WMS 11	AC WMS 16
Minimum and maximum air voids	C.1.3, impact 2x75	PN-EN 12697-8, p. 4	$V_{min2,0}$ V_{max4}	$V_{min2,0}$ V_{max4}
Rutting resistance	C.1.20, roller, P_{98}-P_{100}	PN-EN 12697-22, method B in the air, PN-EN 13108-20, D.1.6, 60 °C, 10 000 cycles	$WTS_{AIR0,10}$ $PRD_{AIR3,0}$	$WTS_{AIR0,10}$ $PRD_{AIR3,0}$
Watersensitivity	C.1	PN-EN 12697-12, conditionin		
Stiffness	C.1. P_{98}-P			
Fatigue resistance	C.1. P_{98}-P			



Typical structures – typ A



Main advantages of HMAC

- Improved and controlled properties of the AC
  - High stiffness
  - Resistance to rutting
  - High resistance to fatigue
- Better durability and designed life of the pavement
- Possible reduction of layer thickness

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Laboratory tests

1. HMAC with different binders and grading

2. HMAC with different aggregates (including local or lower quality)

HMAC with different binders and grading

- Binders:
  - 35/50, 20/30;
  - PMB: DE 30B;
  - multigrade binder (MP 10/20).
- Grading
  - HMAC 12, HMAC 16, HMAC 20

Basic properties

HMAC 12						
Binder			20/30	DE 30B	35/50	MP10/20
Binder content, %m/m			5,0	5,0	5,1	5,3
No.	Property	Unit	Results			
1.	Maximum density	g/cm³	2,605	2,615	2,611	2,602
2.	Bulk density	g/cm³	2,531	2,523	2,532	2,515
3.	Air void content	% v/v	2,8	3,5	3,0	3,3
4.	stability	kN	17,5	16,5	13,0	18,2
5.	flow	mm	3,6	3,8	3,9	3,8
HMAC 16						
Binder			20/30	DE 30B	35/50	MP10/20
Binder content, %m/m			5,1	4,9	5,1	5,3
No.	Property	Unit	Results			
1.	Maximum density	g/cm³	2,578	2,573	2,573	2,574
2.	Bulk density	g/cm³	2,493	2,471	2,494	2,465
3.	Air void content	% v/v	3,3	4,0	3,6	4,2
4.	stability	kN	15,5	17,0	15,2	18,0
5.	flow	mm	3,5	3,7	4,0	4,0
HMAC 20						
Binder			20/30	DE 30B	35/50	MP10/20
Binder content, %m/m			5,3	5,1	5,1	5,1
No.	Property	Unit	Results			
1.	Maximum density	g/cm³	2,532	2,540	2,540	2,540
2.	Bulk density	g/cm³	2,462	2,460	2,457	2,451
3.	Air void content	% v/v	2,8	3,1	3,3	3,5
4.	stability	kN	13,3	18,0	16,9	19,0
5.	flow	mm	3,9	3,7	4,0	4,4

Performance properties

Mixture	Rut depth, %	Stiffness, MPa	Fatigue	
			ε_6, [μm/m]	R^2
HMAC12 20/30	4,8	17813	137	0,98
HMAC12 35/50	>15	12671	-	-
HMAC12 DE 30B	5,3	12823	195	0,94
HMAC12 MP10/20	5,0	16537	139	0,96
HMAC16 20/30	5,2	17950	127	0,89
HMAC16 35/50	>10	11651	-	-
HMAC16 DE 30B	2,8	14037	174	0,75
HMAC16 MP10/20	4,2	14286	140	0,85
HMAC20 20/30	4,5	16009	133	0,78
HMAC20 35/50	>12	12792	-	-
HMAC20 DE 30B	4,5	14107	196	0,69
HMAC20 MP10/20	4,2	13993	137	0,77

HMAC with different aggregates

- Binder 20/30
- Aggregates:
  - Basalt – HMAC 16 B (for comparison)
  - Cobblestone - HMAC16 – C
  - Granite - HMAC16 – G
  - Limestone - HMAC16 – L
  - Steel slag - HMAC16 – S

Results

Property	HMAC16-B, B=4,6 %	HMAC16-B, B=5,1 %	HMAC16-C, B=4,9 %	HMAC16-G, B=5,5 %	HMAC16-L, B=5,5 %	HMAC16-S, B=5,3 %	Requirement HMAC 2007
Mineral mixture density, g/cm³	2,850	2,850	2,691	2,662	2,698	3,645	–
Asphalt density, g/cm³	2,636	2,617	2,493	2,448	2,479	2,312	–
Asphalt bulk density, g/cm³	2,550	2,568	2,419	2,375	2,403	3,115	–
Air voids content, % v/v	3,3	1,9	3	3	3,1	3	3,0 ÷ 5,0
Mean rut depth, %	2,7	6,3	2	2,6	3,7	2,3	≤ 5,0
IT-CY, 10 °C, MPa	21 118	19 272	18 918	17 241	23 511	19 325	–
4PB-PR, complex modulus, 10 °C, MPa	19 756	17 950	16 927	17 291	19 837	20 713	≥ 14 000
Fatigue damage D, %	> 50	49	19,7	> 50	31,7	15,3	≤ 50
Water sensitivity, %	114,9	118,7	104,8	107,8	95,3	121,3	≥ 80,0

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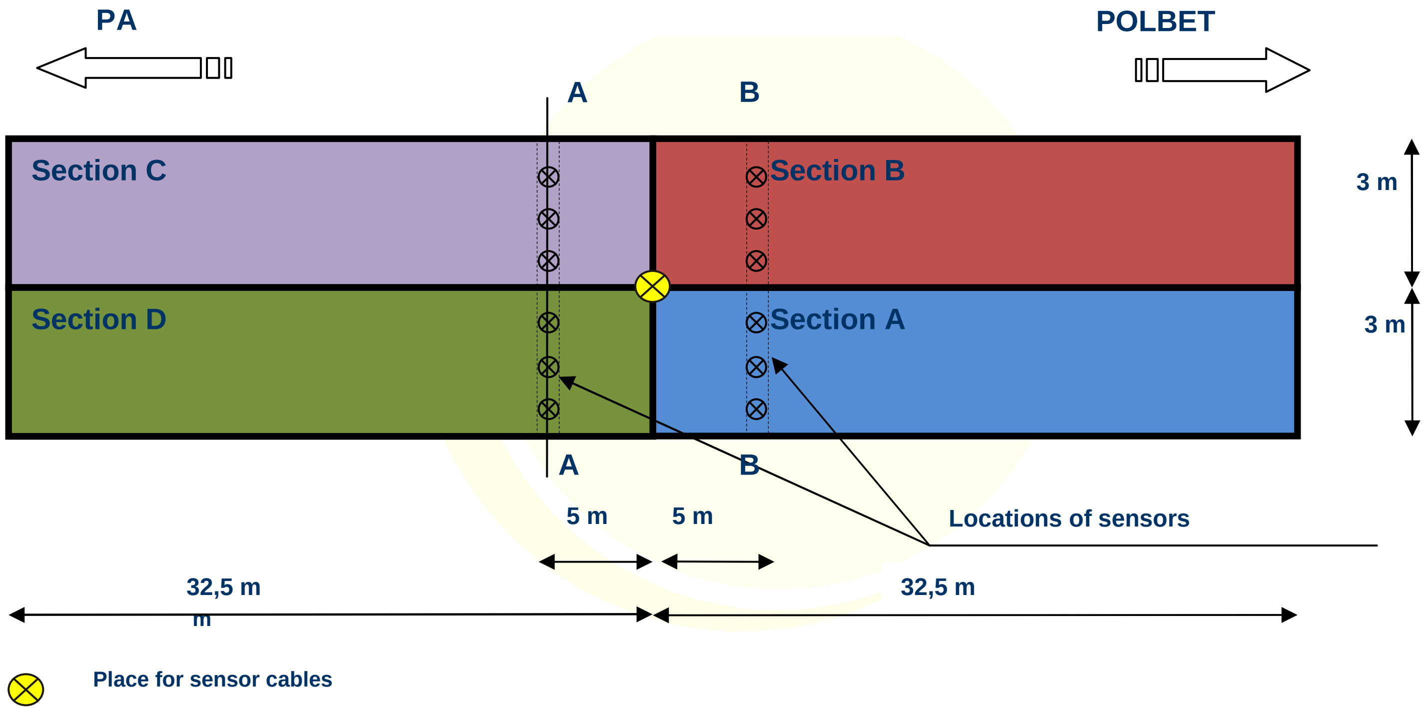
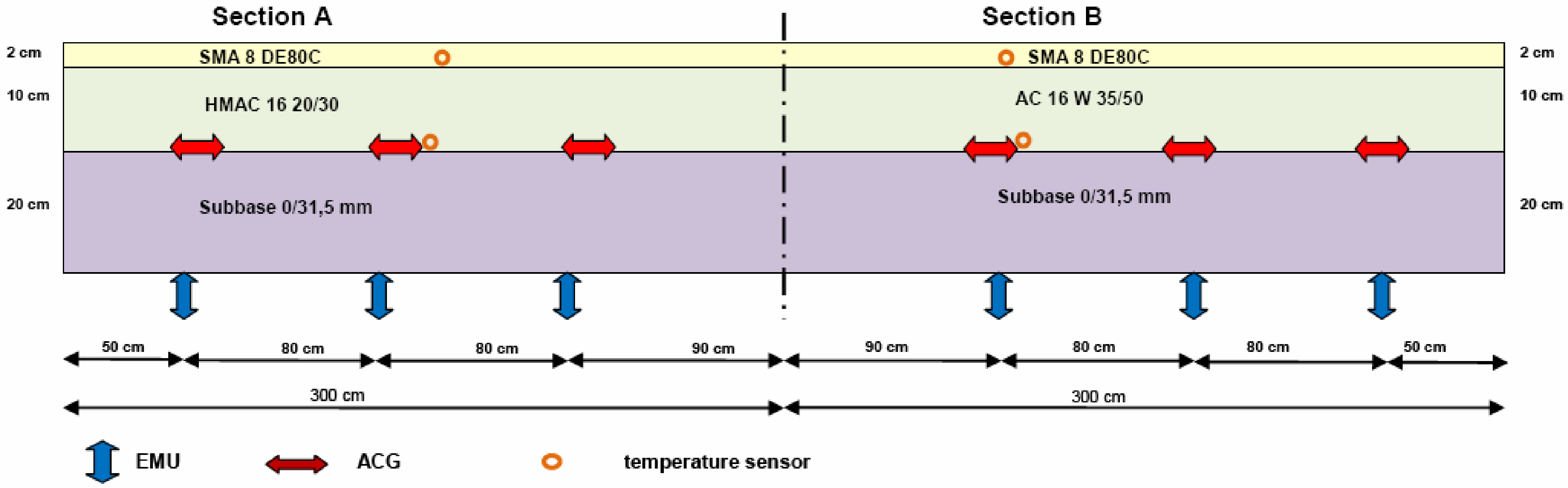
Location & Bird's eye view

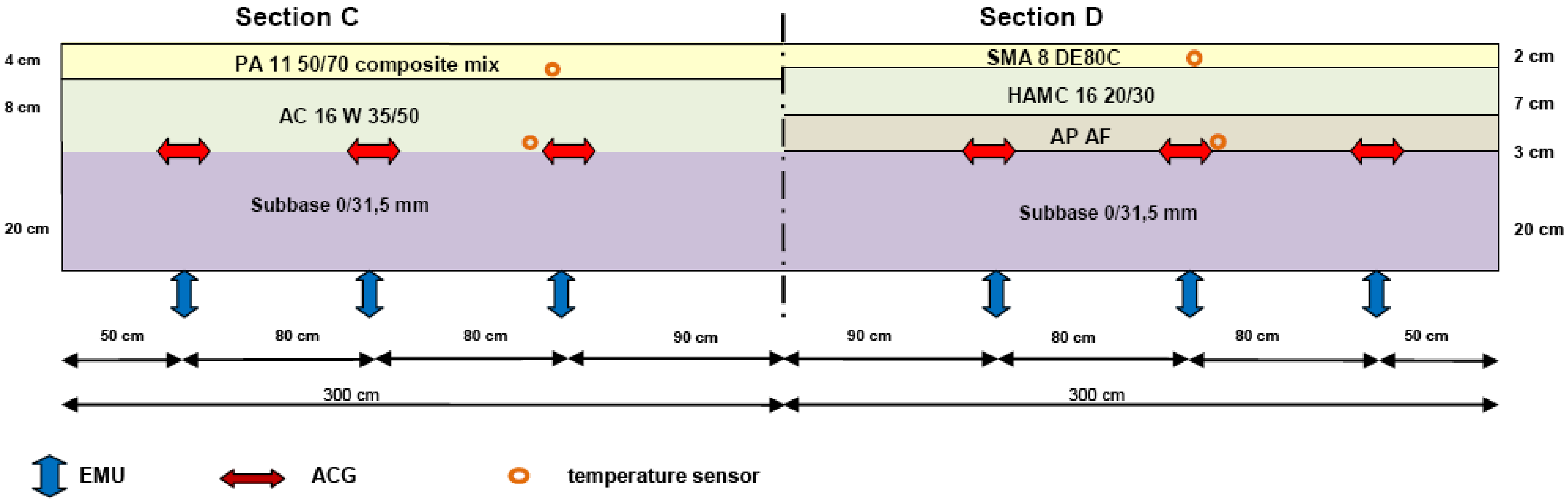


Section A & B



Section A
Section B
2 cm
10 cm
20 cm
SMA 8 DE80C
HMAC 16 20/30
Subbase 0/31,5 mm
SMA 8 DE80C
AC 16 W 35/50
Subbase 0/31,5 mm
2 cm
10 cm
20 cm
50 cm
80 cm
80 cm
90 cm
90 cm
80 cm
80 cm
50 cm
300 cm
300 cm
EMU
ACG
temperature sensor

Section C & D



Section C
Section D
4 cm
8 cm
20 cm
PA 11 50/70 composite mix
AC 16 W 35/50
Subbase 0/31,5 mm
SMA 8 DE80C
HAMC 16 20/30
AP AF
Subbase 0/31,5 mm
2 cm
7 cm
3 cm
20 cm
50 cm
80 cm
80 cm
90 cm
90 cm
80 cm
80 cm
50 cm
300 cm
300 cm
EMU
ACG
temperature sensor

Mixtures

SMA 8 DE80C (WT NA DiL 2008):

- DE80C
- Limestone filler
- **Basalt (Sulików)**
- Viatop Premium
- Wetfix BE
- Sasobit

AC 16 W 35/50 (WT NA DiL 2008):

- 35/50
- Limestone filler
- **Dolomite (Radkowice)**

Mixtures (2)

AC WMS 16 20/30 (WT NA DiL 2008) (fundamental approach)

- 20/30
- Limestone filler
- **Limestone (Kujawy)**

AP AF (sand mix PN-S-96025) **antyfatigue**

- DE 80C
- Natural and crushed sand
- Limestone filler
- Fiber TOFIC
- Wetfix BE
- Sasobit

Composite mix „STRABAPHALT" (PA 11 50/70, WT NA DiL 2008)

- 50/70,
- Malphyre (Czarny Bór)
- Water-cement mortar

Properties of designed mixes

	SMA 8 DE80C	AC 16 35/50	ACWMS 16 20/30
Am, % m/m	7,1	4,3	5,5
Wp, % v/v	3,3	3,8	3,8
WTS_{AIR}	0,04	0,03	0,08
PRD_{AIR}	5,6	1,0	2,7
P, % (LCPC)	9,2	2,1	3,6
ITSR, %	92,6	90,2	91,8
S, MPa	-	19435	16312
ε_6, µm/m	-	116	180

Mix design results

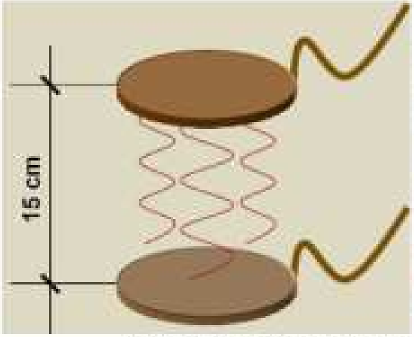
Mix design according to WT NA 2008

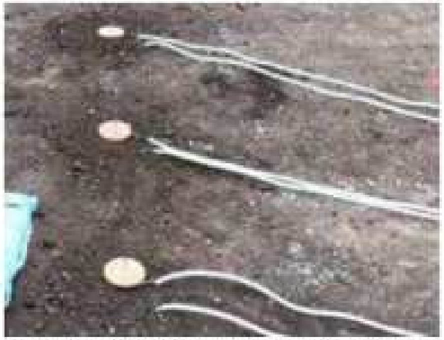
All requirements fulfilled

Good performance :

- Fatigue
- Stiffness
- Rutting (small and large device)
- Resistance to water

Construction works





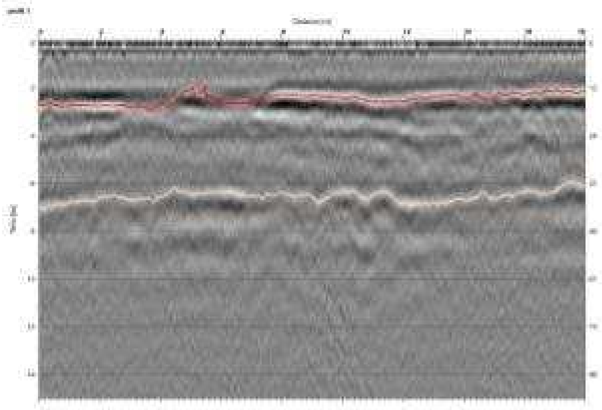
Fot. 1 Podłączenie czujników (EMU) w warstwie podłoża

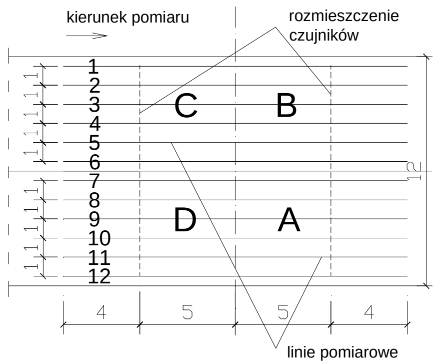
Fot. 2 Czujniki odkształceń (ASG) na warstwie podbudowy z kruszywa łamanego stabilizowanego mechanicznie

Fot. 3 Prace przy wykonaniu oraz widok warstwy ścieralnej SMA 8 DE80C

Layer thickness

	Thickness of asphalt layers, mm			
	Section A	Section B	Section C	Section D
Slabs	15,0	11,7	13,5	14,5
Cores	15,0	11,8	13,4	14,3
Wearing course	2,4	1,8	4,8	2,2
Base course	12,6	10,0	8,6	7,5
AP AF Layer	-	-	-	4,6



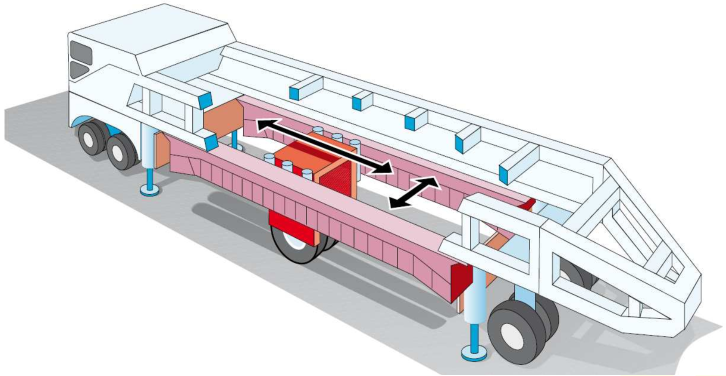


SPENS

HVS

FEHRL

Testing conditions HVS



Single wheel

Wheel Load: 60 kN (80 kN)*

Tire pressure: 800 kPa

Speed: 10-12 km/h

Temperature: +10 °C

Number of loads 300 000 cycles

Measurements done by VTI

The type and frequency of the measurements are listed below:

Transverse profile	daily
Vertical displacement of the subgrade	daily
Vertical permanent deformation of the subgrade	daily
Transverse horizontal strain in the bottom of asphalt layers	daily

Measurements frequency for subsequent loading levels:

Transverse horizontal strain in the bottom of asphalt layers (second and the last day of the testing)

Vertical displacement of the subgrade (second and the last day of the testing)

Wheel loading: 30, 40, 50 and 60 kN

Central position of the wheel in transverse direction

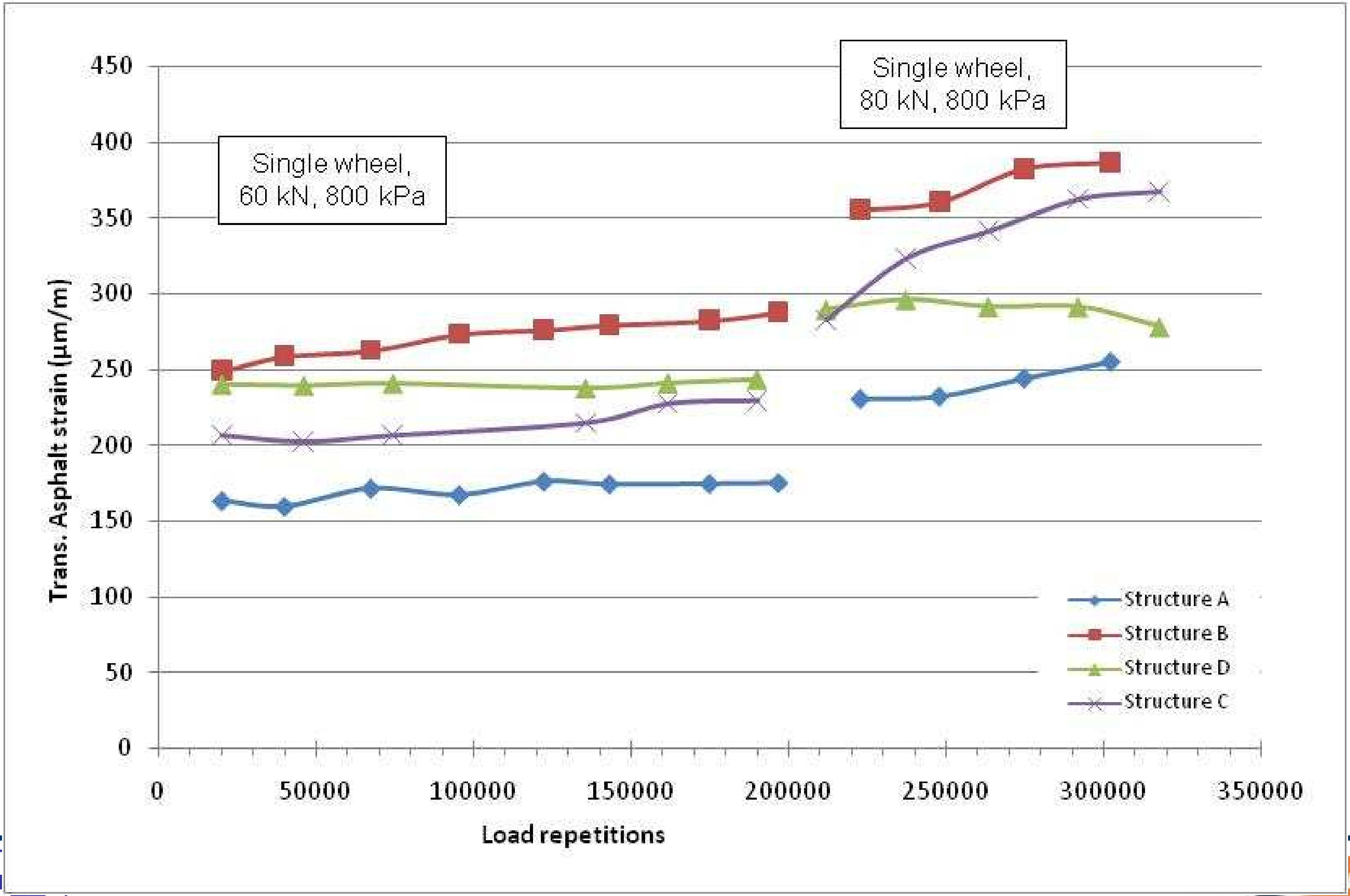
Complementary testing programm

- FWD
- Thickness: cores + GPR
- Coring
- Composition and compaction
- Stiffness ITCY, 4PB
- Fatigue 4PB

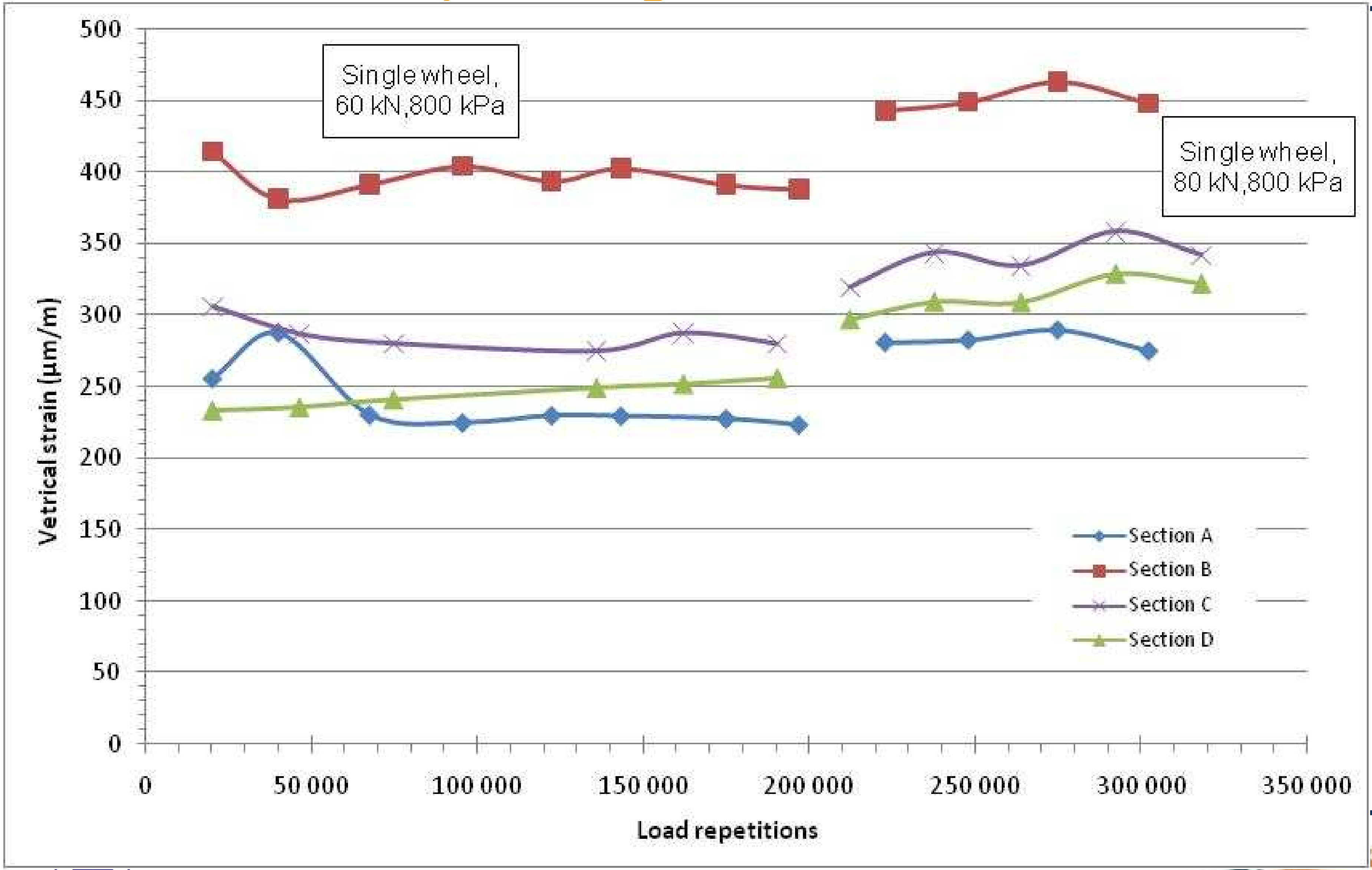
  * Tests on loaded and not loaded areas

Profile deformation of wearing course

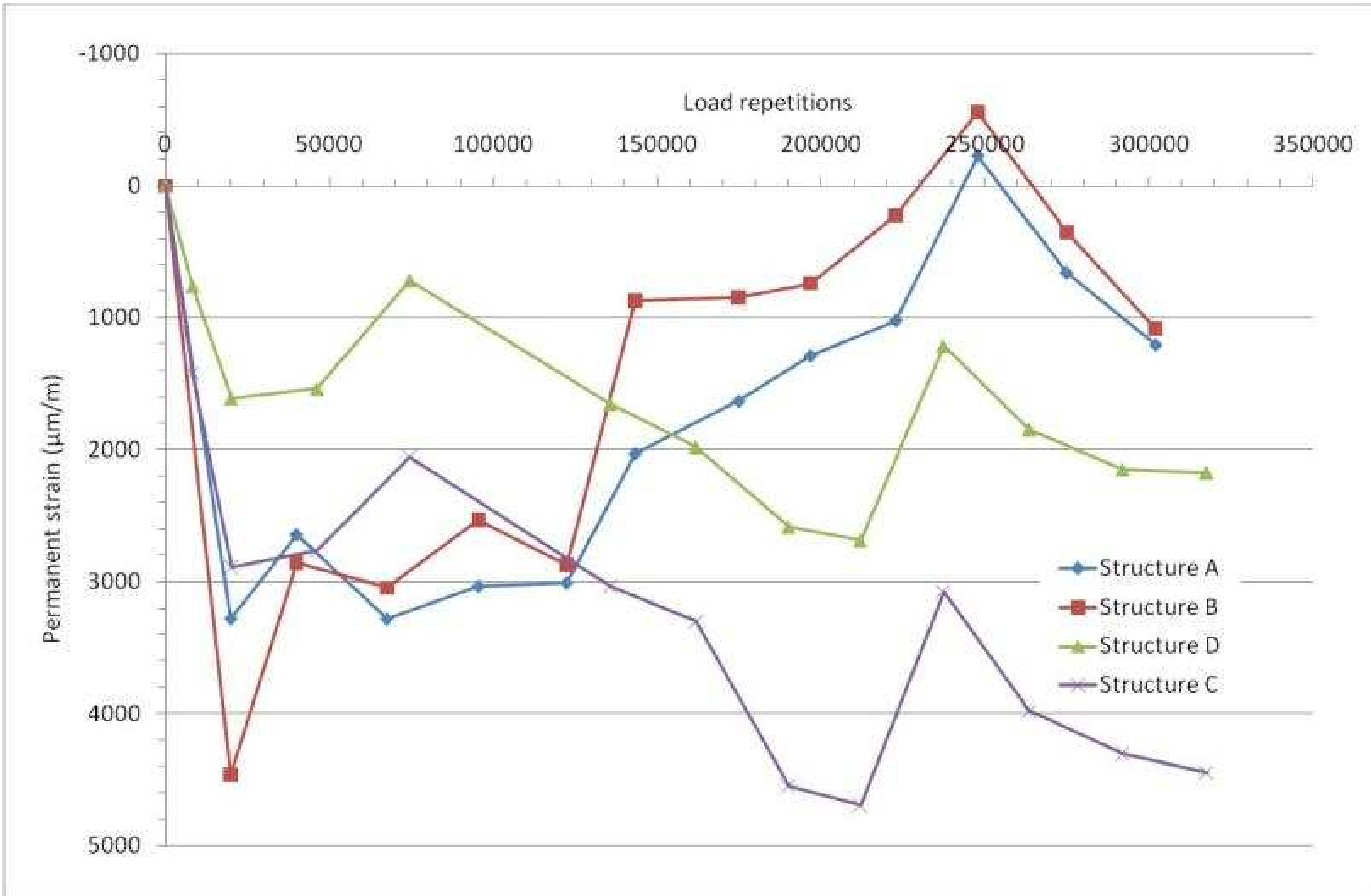
Tensile strains at the bottom of asphalt layers



Strain in the top of subgrade



Permanent strain in the subgrade



Visual inspection

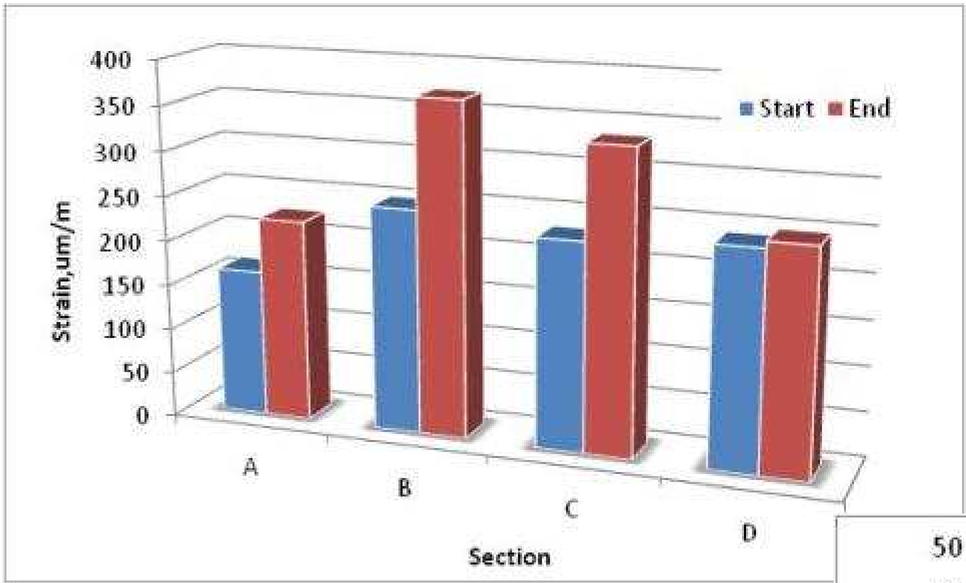
Black path

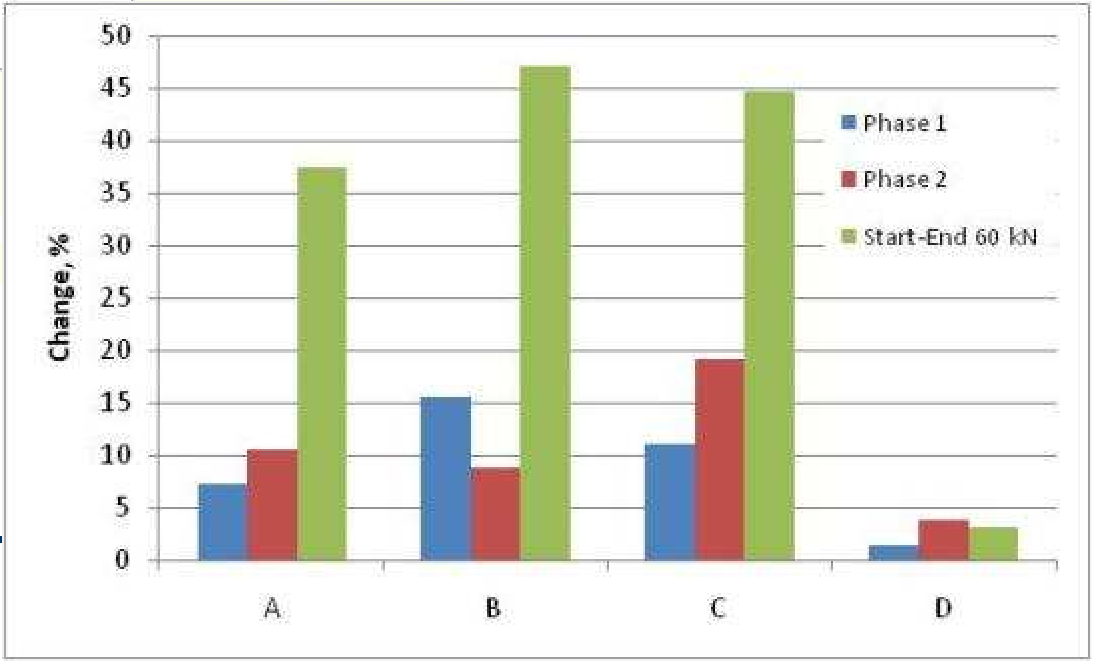
Good state of wearing course

No cracks

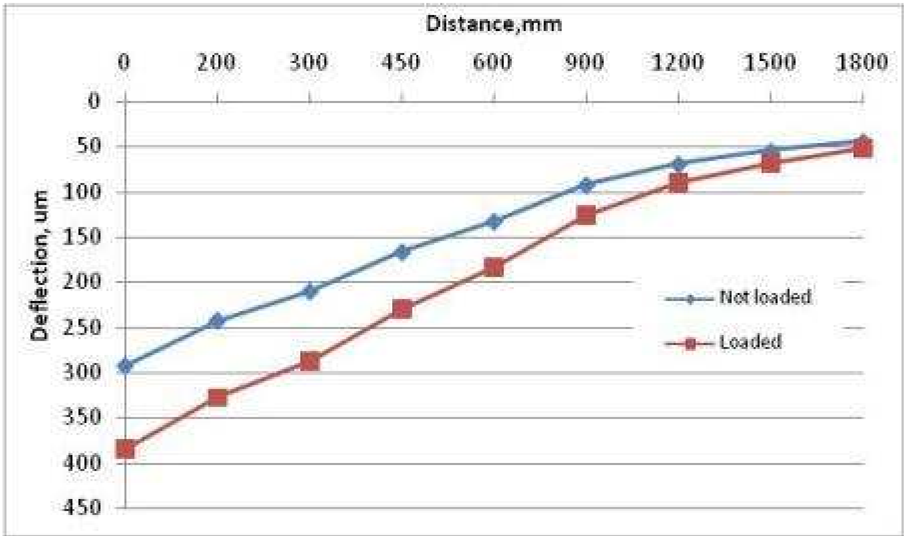
Small deformation

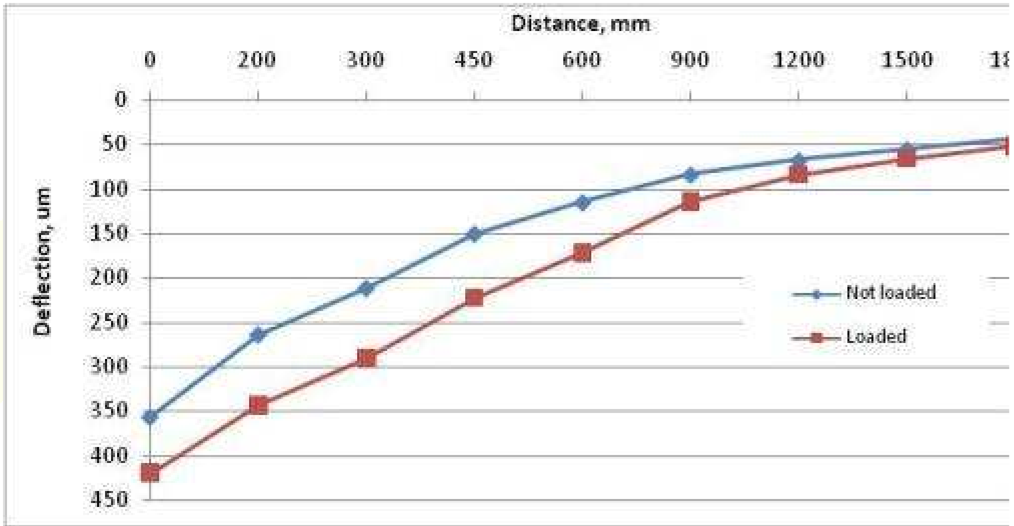
Fatigue damage?

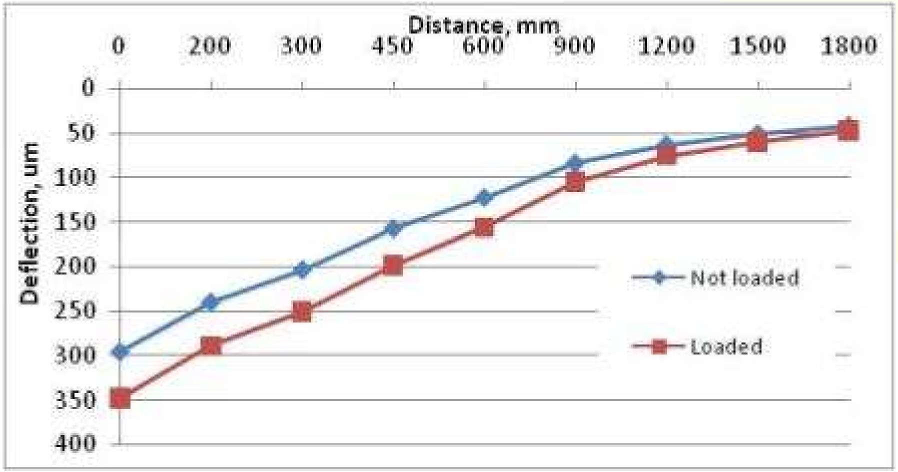


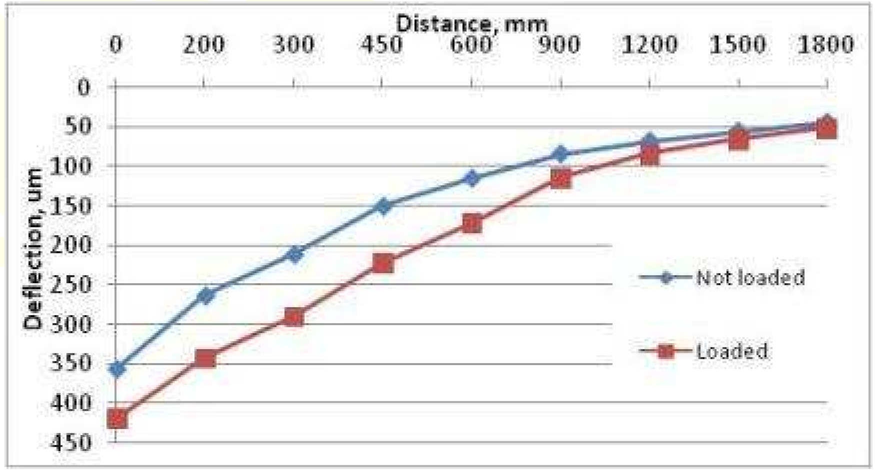


FWD test results

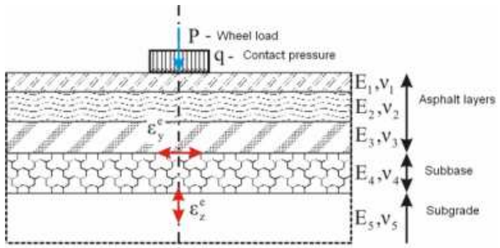






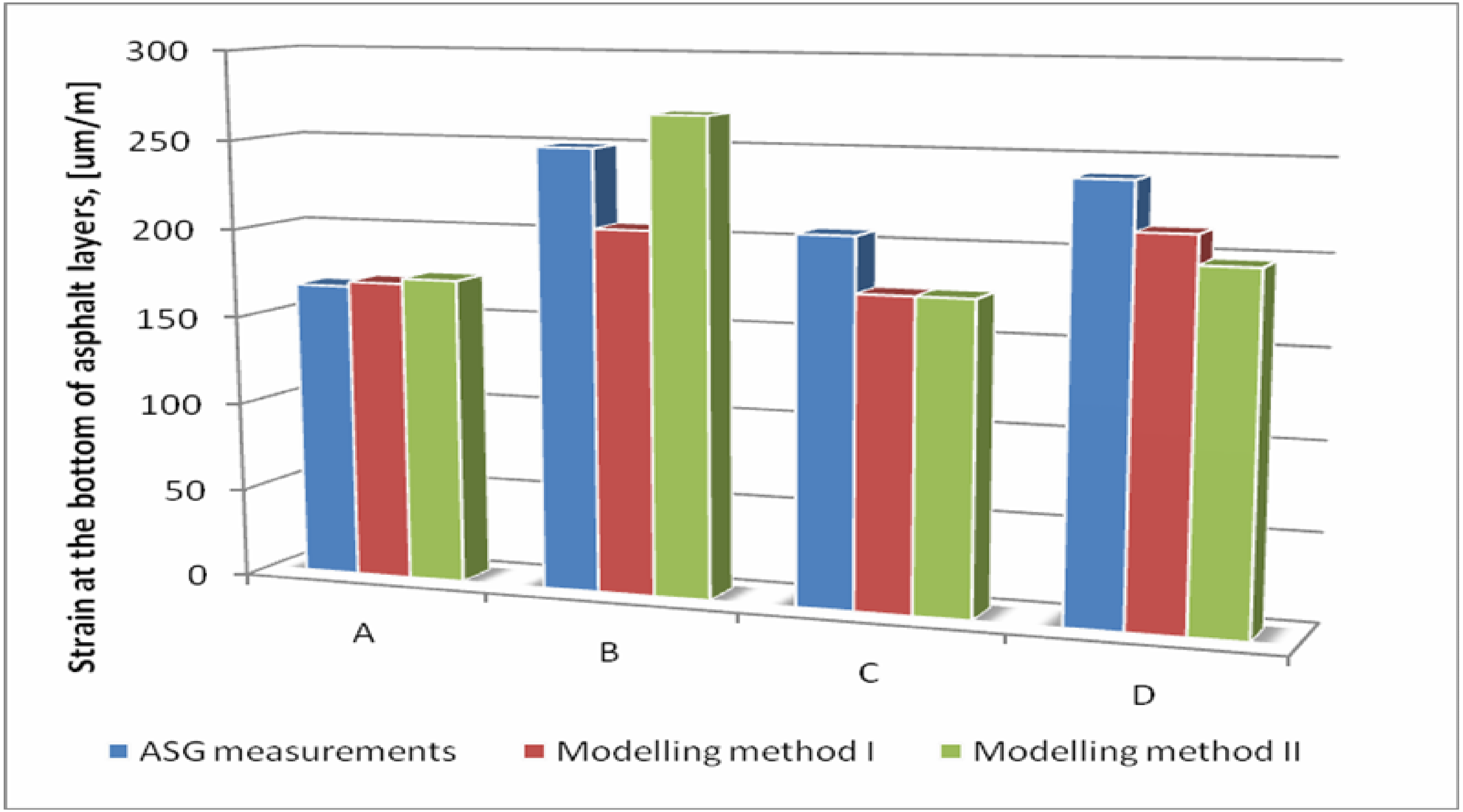


Modelling

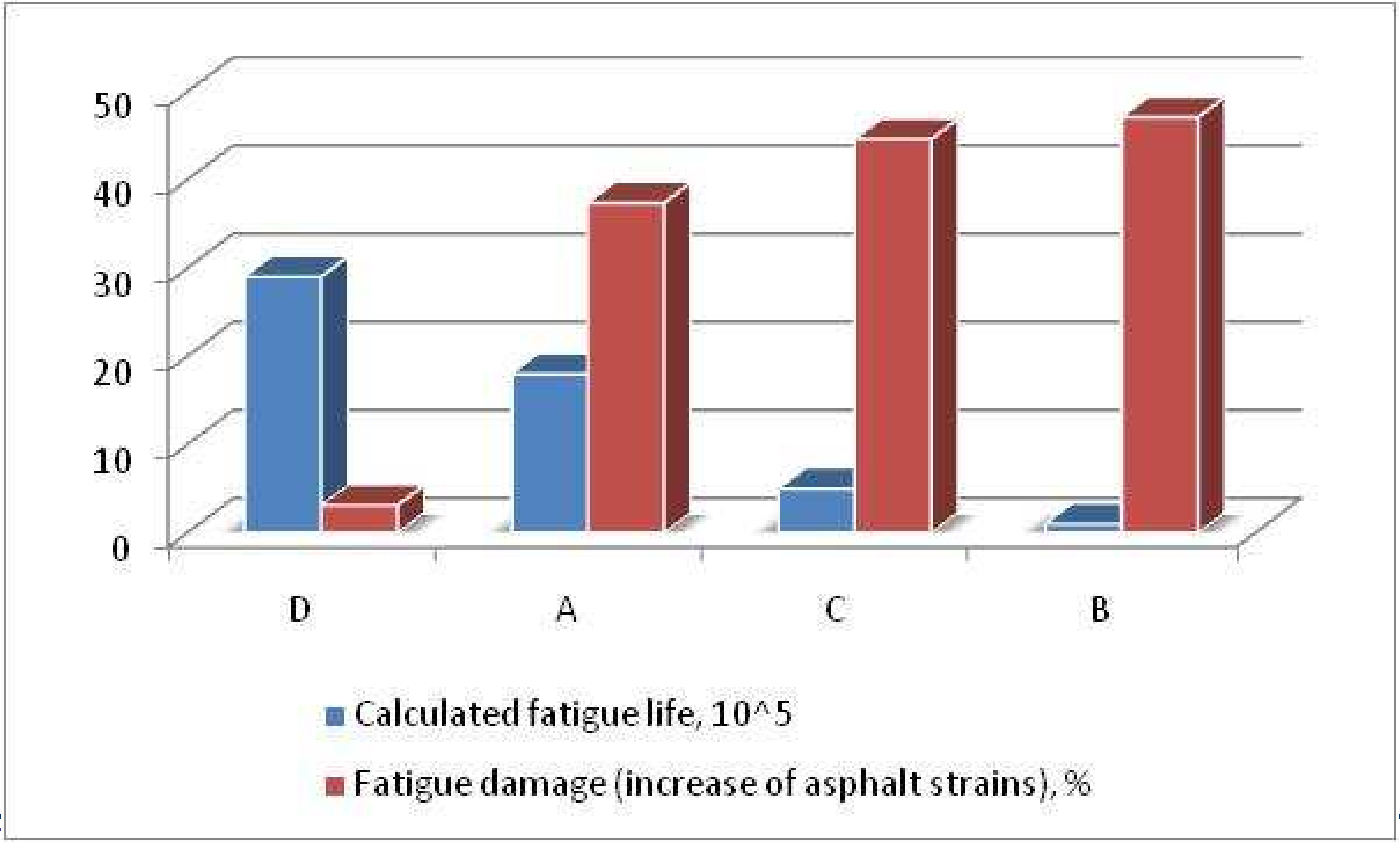


Wheel load 60kN		Wheel load 80kN		Fatigue life according to IA (mln)		Fatigue life according to laboratory tests (mln)		Fatigue life taking into account strain in soil base (mln)	
ε_{asf}, µm/m	ε_{grunt}, µm/m	ε_{asf}, µm/m	ε_{grunt}, µm/m	60 kN	80 kN	60 kN	80 kN	60 kN	80 kN
Section A									
170	-570	202	-740	1,9	1,1	1,3	0,4	0,3	0,1
Section B									
205	-736	234	-948	0,3	0,2	5,6	2,7	0,1	0,03
Section C									
175	-550	206	-711	0,5	0,3	0,16	0,06	0,36	0,11
Section D									
86*	-626	99	-809	17,5	11,0	135,0	53,3	0,2	0,06
213		250		2,2	1,3	4,5	1,8		

Modelling vs measurements

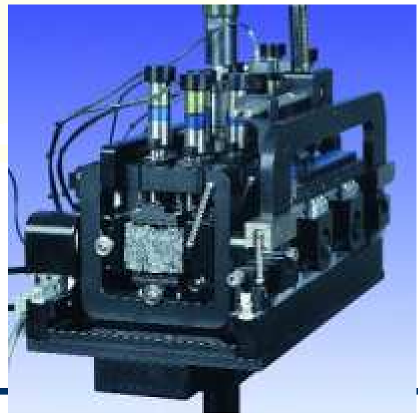


Damage vs predicted life



4PB - test methods and goals

1. **Stiffness 4PB** (PN-EN 12697-26) 10˚C, 10Hz
- Parameters for modelling
- Damage evaluation (lost of stiffness)
2. **Fatigue 4PB** (PN-EN 12697-24) 10˚C, 10Hz
- Fatigue law (18-20 beams per mix)
- Damage (lost of fatigue resistance)



Specimens

1. Specimens prepared in laboratory

HMAC 16 rec

AC 16 rec

PA rec

2. Specimens cut from the pavement

Loaded areas (wheel paths):

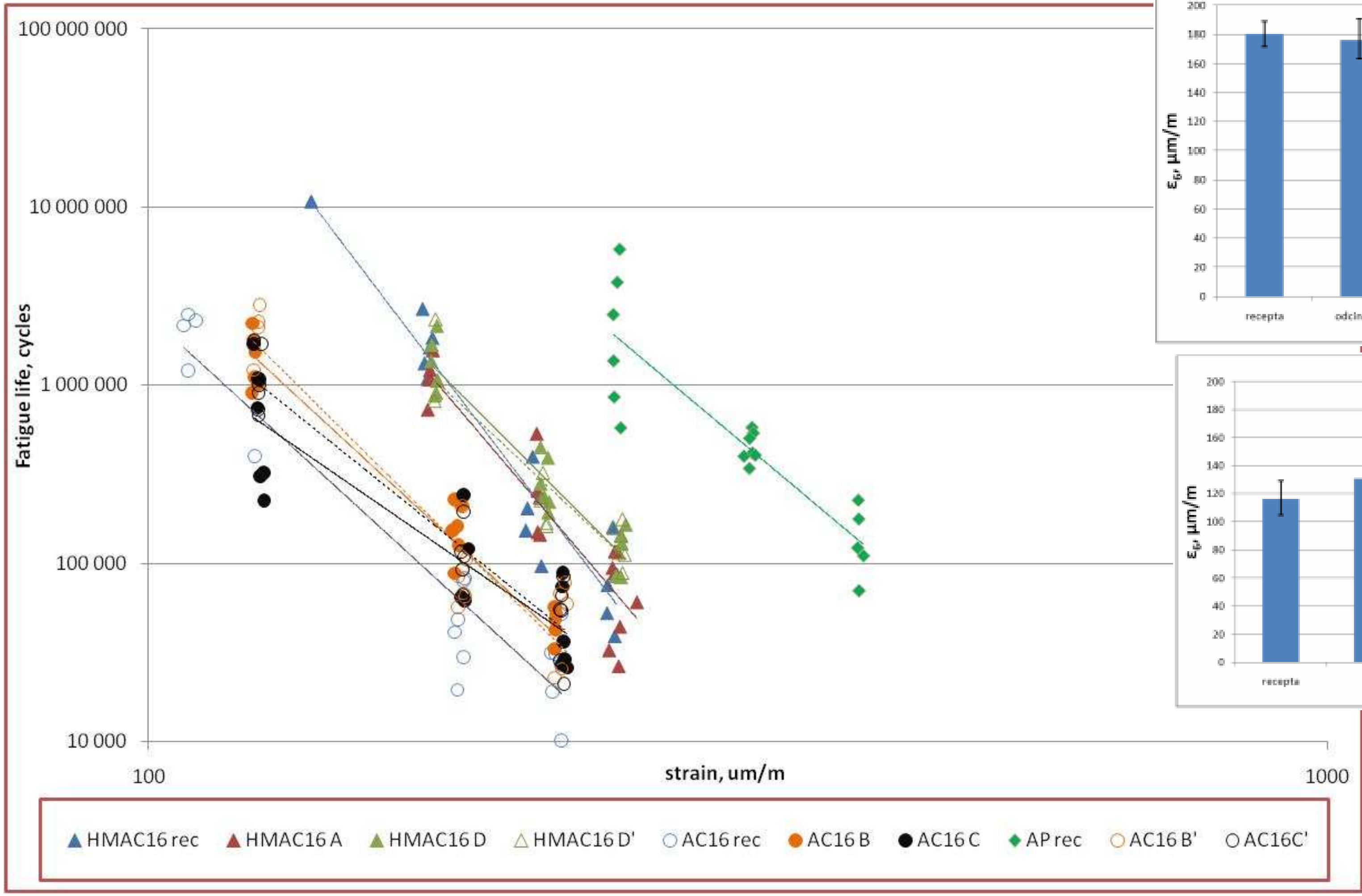
- HMAC 16 A and HMAC 16 D
- AC 16 B and AC 16 C

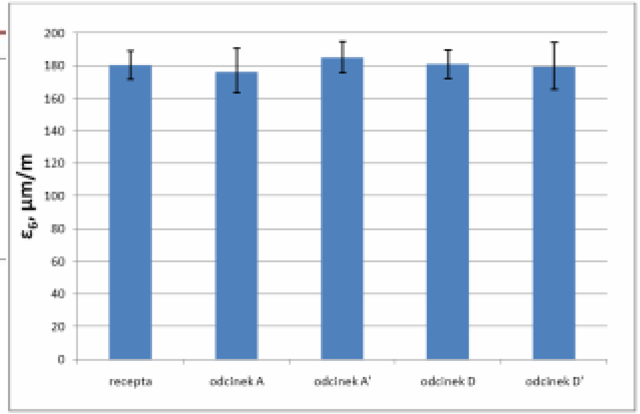
Not loaded areas:

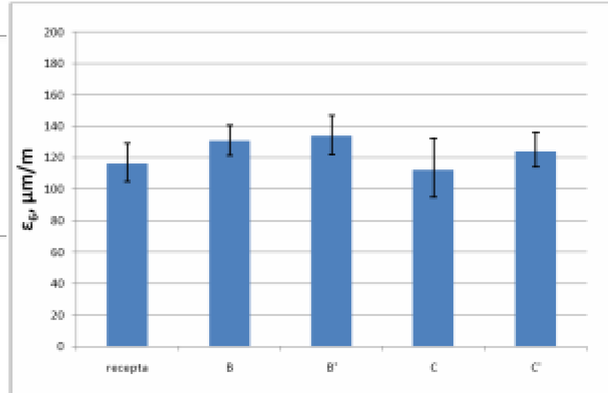
- HMAC 16 A′ and HMAC 16 D′
- AC 16 B′ and AC 16 C′

Fatigue:
11 full test
≈215 specimens
≈140 mln cycles
≈ 160 days/24h

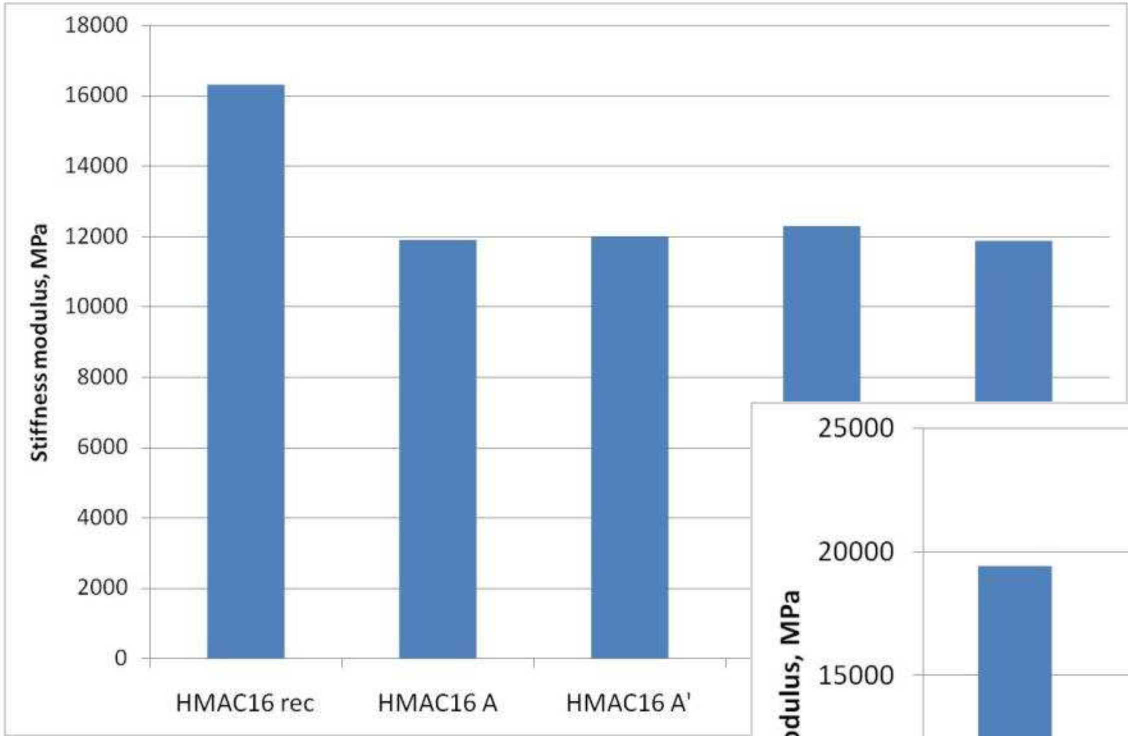
Fatigue life, 4PB

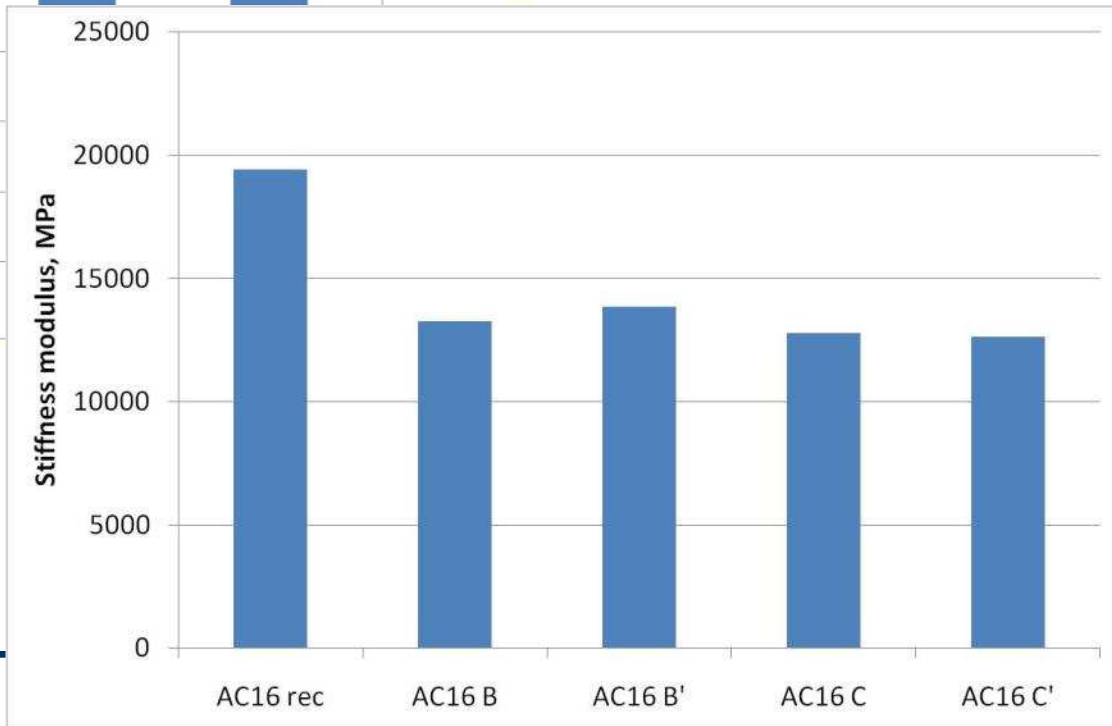






Stiffness, 4PB





Healing

- **Healing** – it is phenomena of recovery of mechanical properties (stiffness, fatigue resistance) during rest period
- Hot summer days (June/July 2008),
- Pavement HVS test temperature 10°C,
- FWD test – in 2-3 days after HVS removing
- Coring – middle August (5-6 weeks later)
- Rapid increase of temperature could close microcracks and could recover mechanical properties - healing

General assesement of pavements

- Loadings 200 000 (wheel load 60 kN) + 100 000 (wheel load 80 kN) in 14 days
- Equivalent to 700 000 of 100 kN axle loads
- Traffic category KR3 (20 years)
- Structures – thickness for KR2/KR3
- Structures were not destroyed
- Better performance of HMAC structures
- Promissing effectiveness of antyfatigue layer
- Good performence of HMAC based on limestone aggregates

HMAC – main conclusions

- Modern test methods gives reliable evaluation of properties of HMAC
- Good, controlled performance properties – resistance to rutting, water sensitivity
- Improved resistance to fatigue, higher stiffness
- Higher durability and designed life of the pavement
- Potential reduction of asphalt layer thicknesses
- Lower quality aggregates can be succesfully used for HMAC
- Fundamental approach – benefits for investor, contractors and users
- Future – continuation of HMAC development and common use fundamental approach

THANK YOU!