SEMINARIO INTERNACIONAL DE PAVIMENTOS DE HORMIGÓN

INSTITUTO DEL CEMENTO PORTLAND ARGENTINO

Whitetopping ultra delgado e incorporación de fibras para pavimentos de hormigón de bajo espesor

José T. Balbo, Prof. Associado – USP

Vice-Presidente – ISCP

Secretario Ejecutivo - IBRACON

Córdoba – Argentina

25 de Octubre de 2012

La investigación sobre *Whitetopping* Ultra-delgado en Brasil

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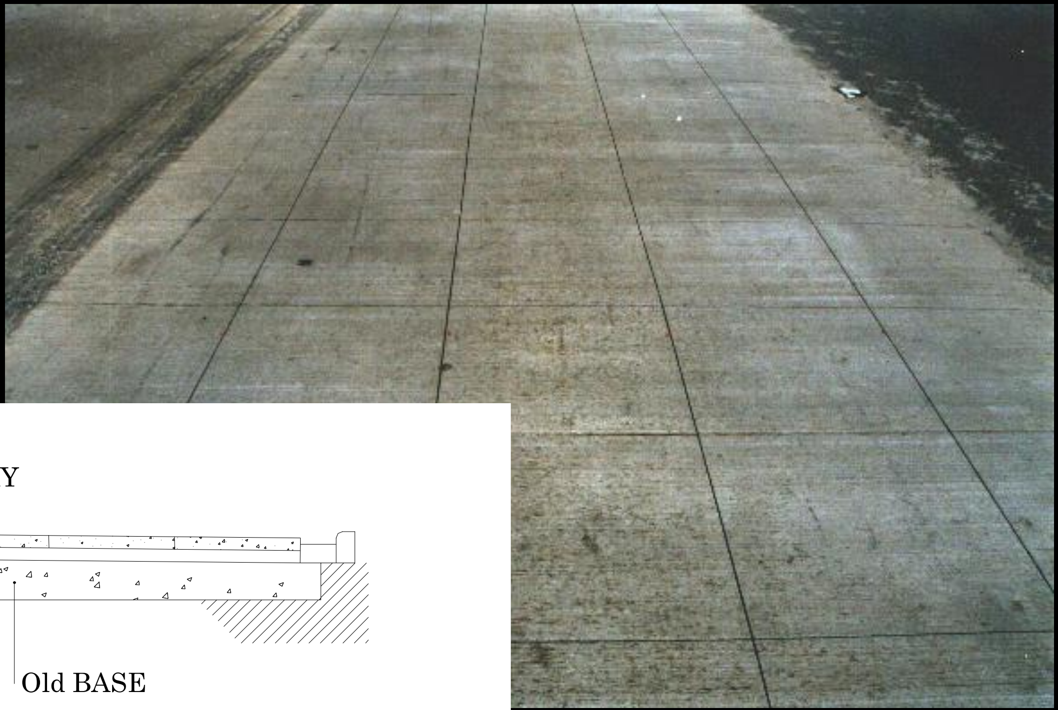
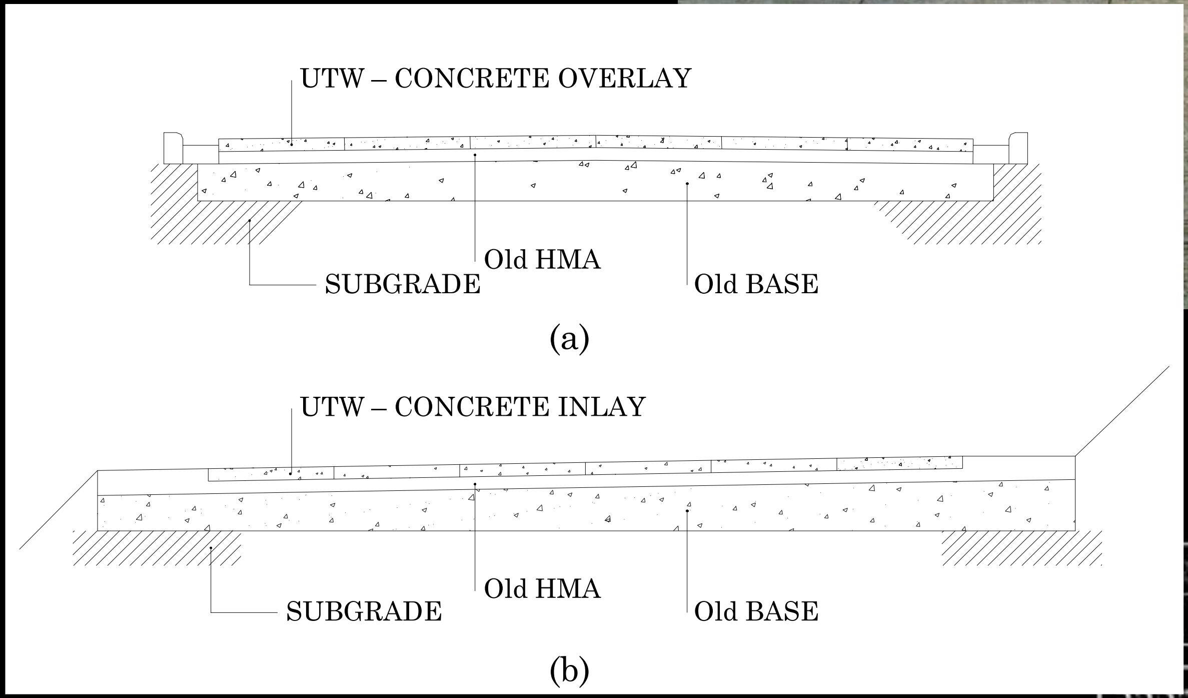
¿Lo que se *Whitetopping*?

Courtesy: Valéria Ganassalli

¿Lo que se *Whitetopping Ultradelgado*?





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¿Por qué emplear losas de hormigón como superposición en pavimentos de asfalto viejos?

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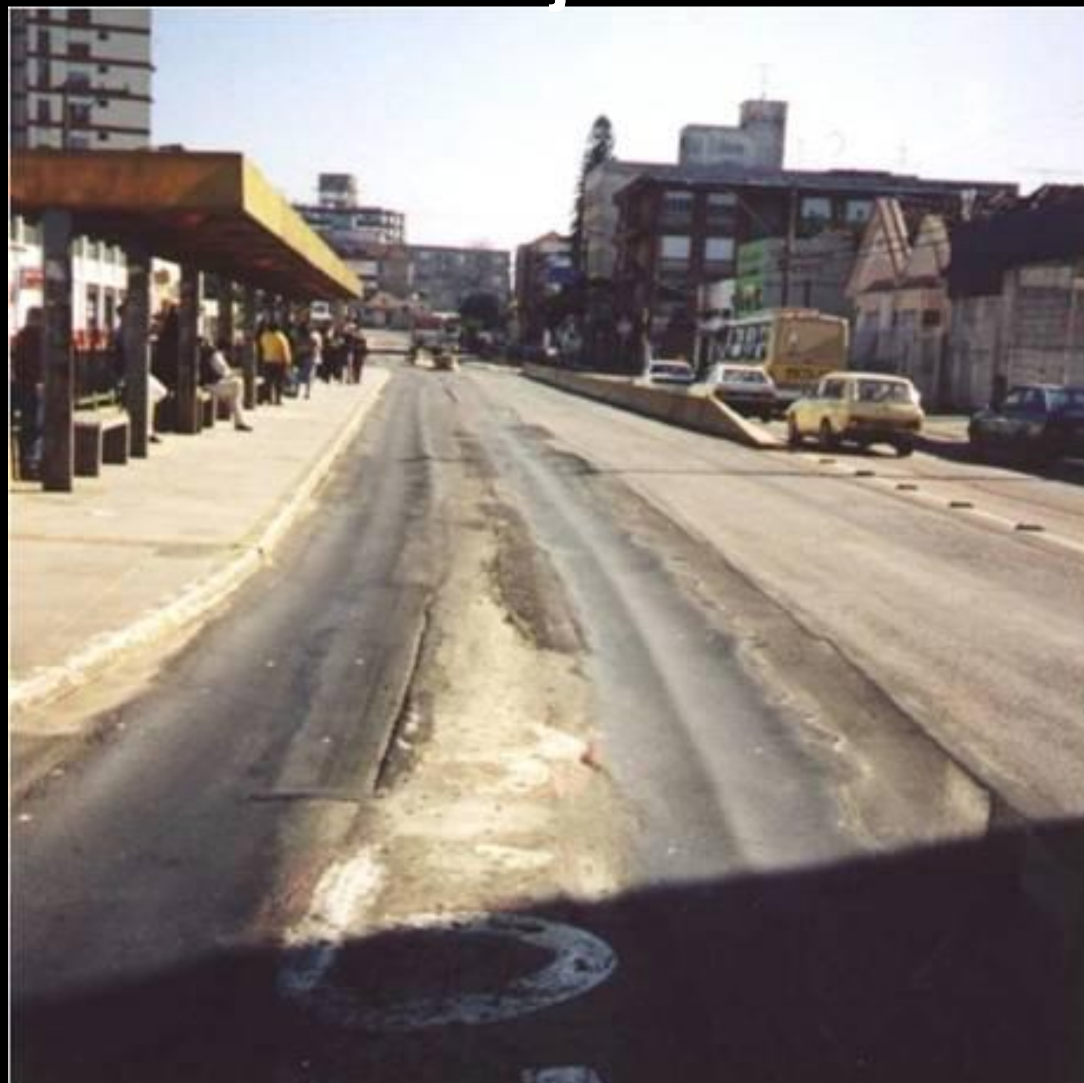
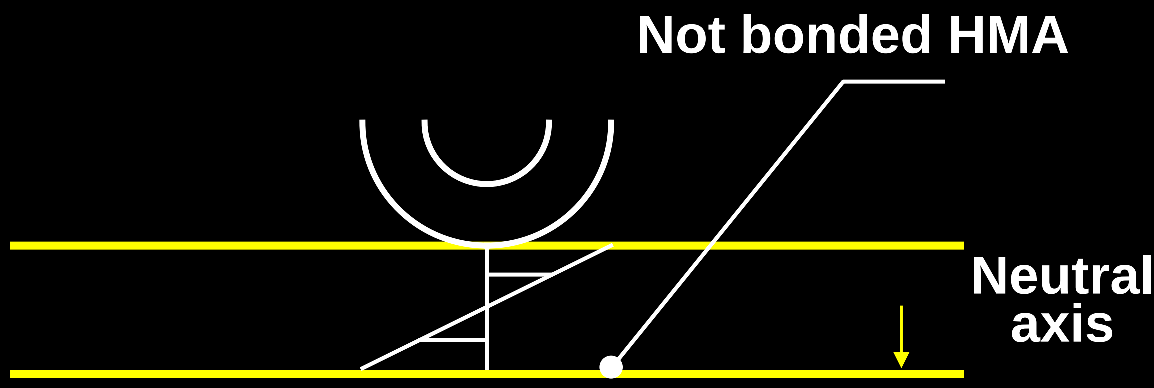
¿Por qué emplear losas de hormigón como superposición en pavimentos de asfalto viejos?



Bernucci et al, 2006

¿Por qué enlace a la capa de asfalto se requiere?



Situación típica de Losa de Hormigón non adherente

Souce: ABCP,2000

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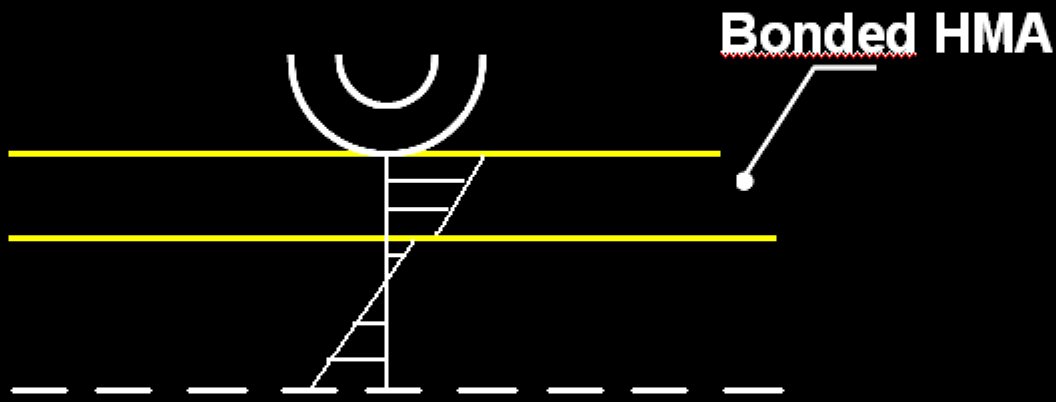
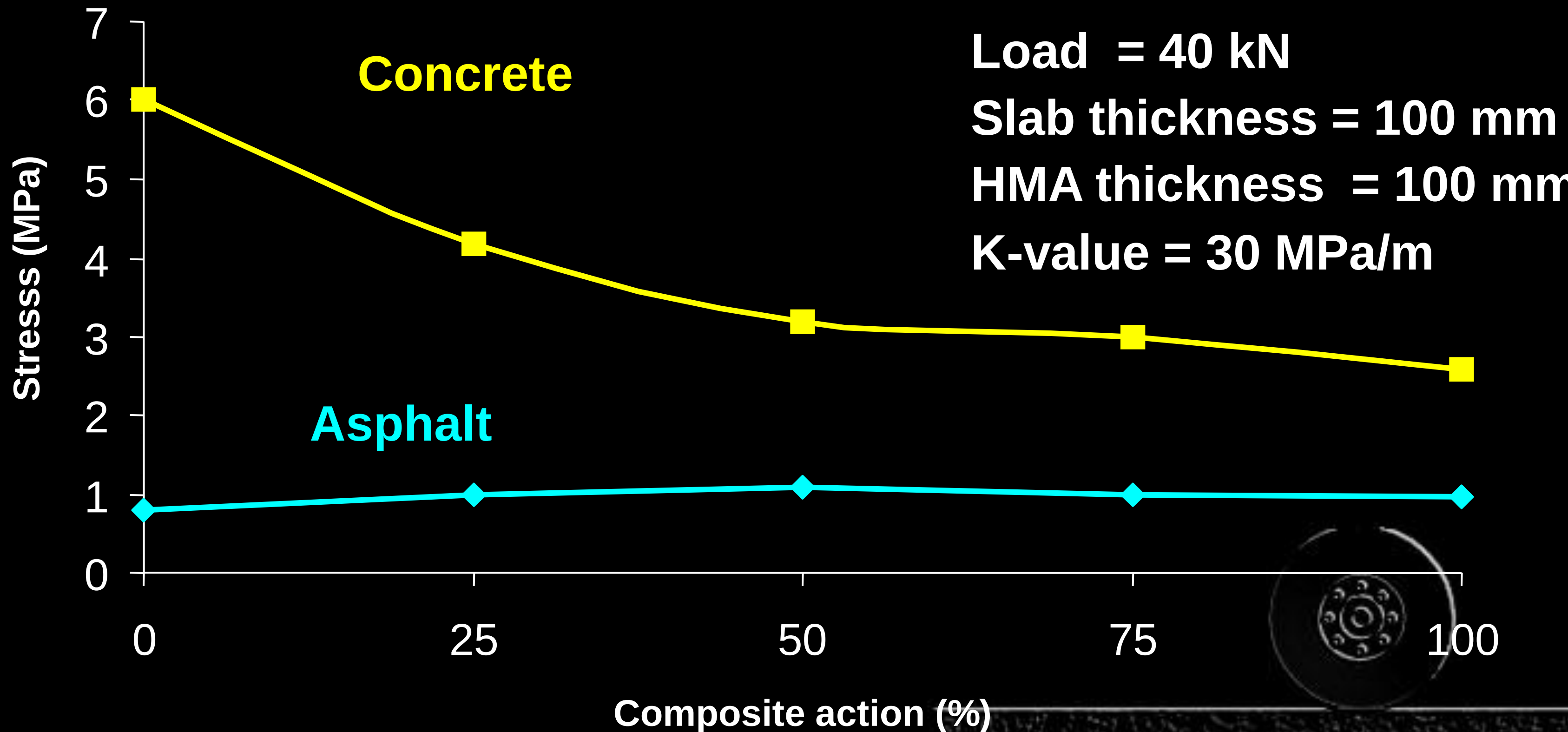
¿Por qué enlace a la capa de asfalto se requiere?



Souce: ABCP,2000

Efecto de la interface adherida en las tensiones



Souce: ABCP,2000

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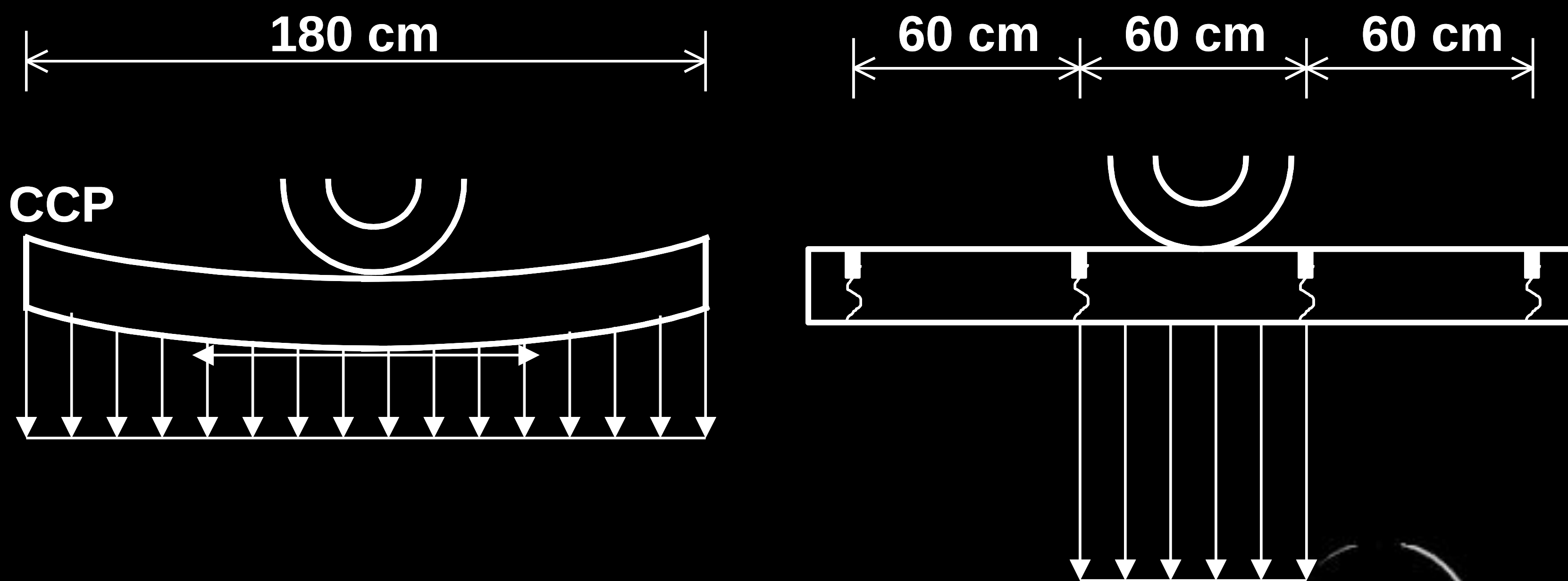
Efecto de losas cortas sobre la distribución de presión



Souce: ABCP,2000

Los estudios de campo en Brasil

<u>1997</u>

SP 280 – Sao Paulo SP
DOT – Brazilian PCA

<u>1999</u>

Parada de bus en la
USP Campus

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1997 UTW

SP-280 Highway

Brazilian PCA and SP-DOT

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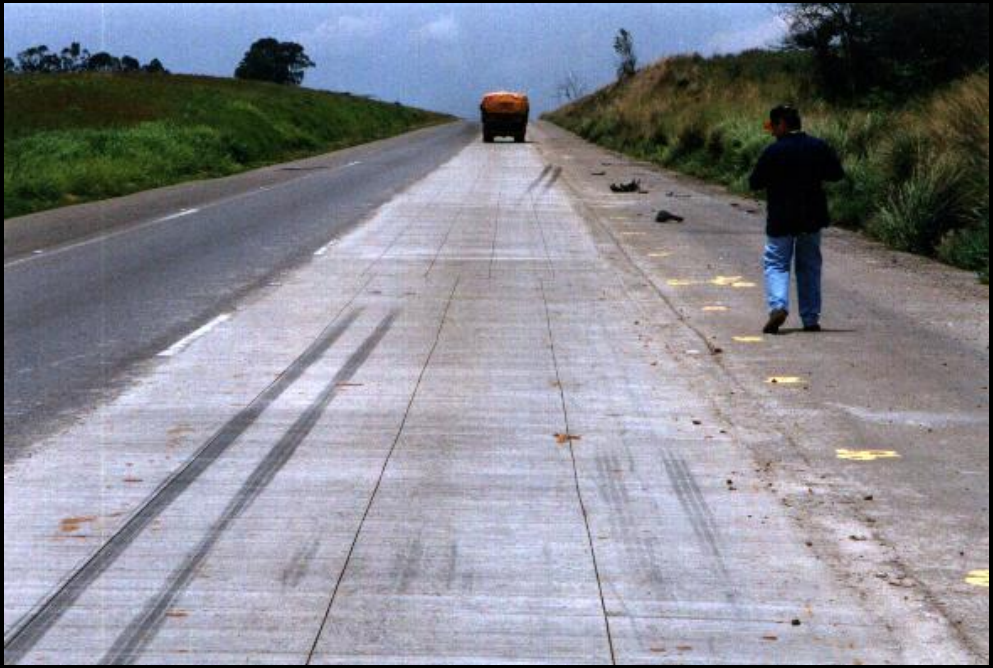
Construction of the Experimental UTW

UTW Design:

6 sections

546 m long (Brazilian PCA)



Existing pavement structure:

HMA : 180 to 200 mm (1,200 MPa - cracked)

Soil-cement base (30 years old) : 100 mm (300 MPa)

Lateritic Sand soil (200 MPa)

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Construction of the Experimental UTW

Section	UTW thickness (mm)	Milled thickness (mm)	Joint spacing (m)
A1	80	7,9	≈ 1,15
B1	80	7,5	≈ 0,80
C1	80	8,2	≈ 0,65
A2	100	9,5	≈ 1,625
B2	100	9,5	≈ 1,15
C2	100	9,4	≈ 0,80

Construction of the Experimental UTW

Fast Setting Cement (kg/cm)	476
Silica Fume (kg/cm)	28.5
Sand (kg/cm)	642
Crushed stone diam. max. 19 mm (kg/cm)	1,029
Water/(cement+silica) ratio	0.40
Plasticizer (L/cm)	1.43
Super-plasticizer (L/cm)	2.38
Slump test at field (mm)	140
Flexural strength at 7 days (MPa)	7.0
Flexural strength at 28 days (MPa)	7.1
Modulus of elasticity at 28 days (MPa)	38,000

Degradation Mode of UTW

Brazil - 1997

Florida - 1997

Souce: Tia et al., 1998

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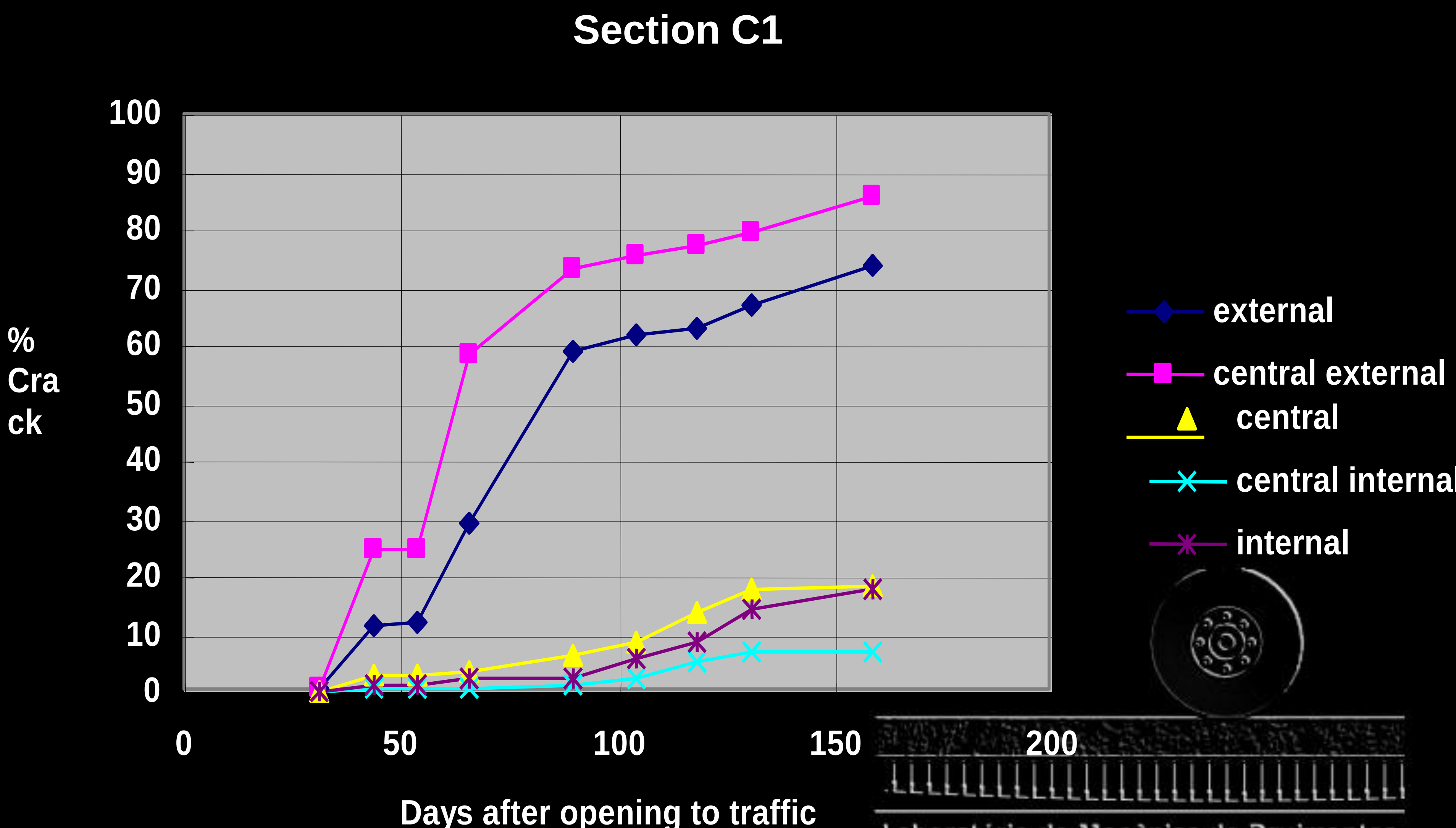
Monitoring the Experimental UTW



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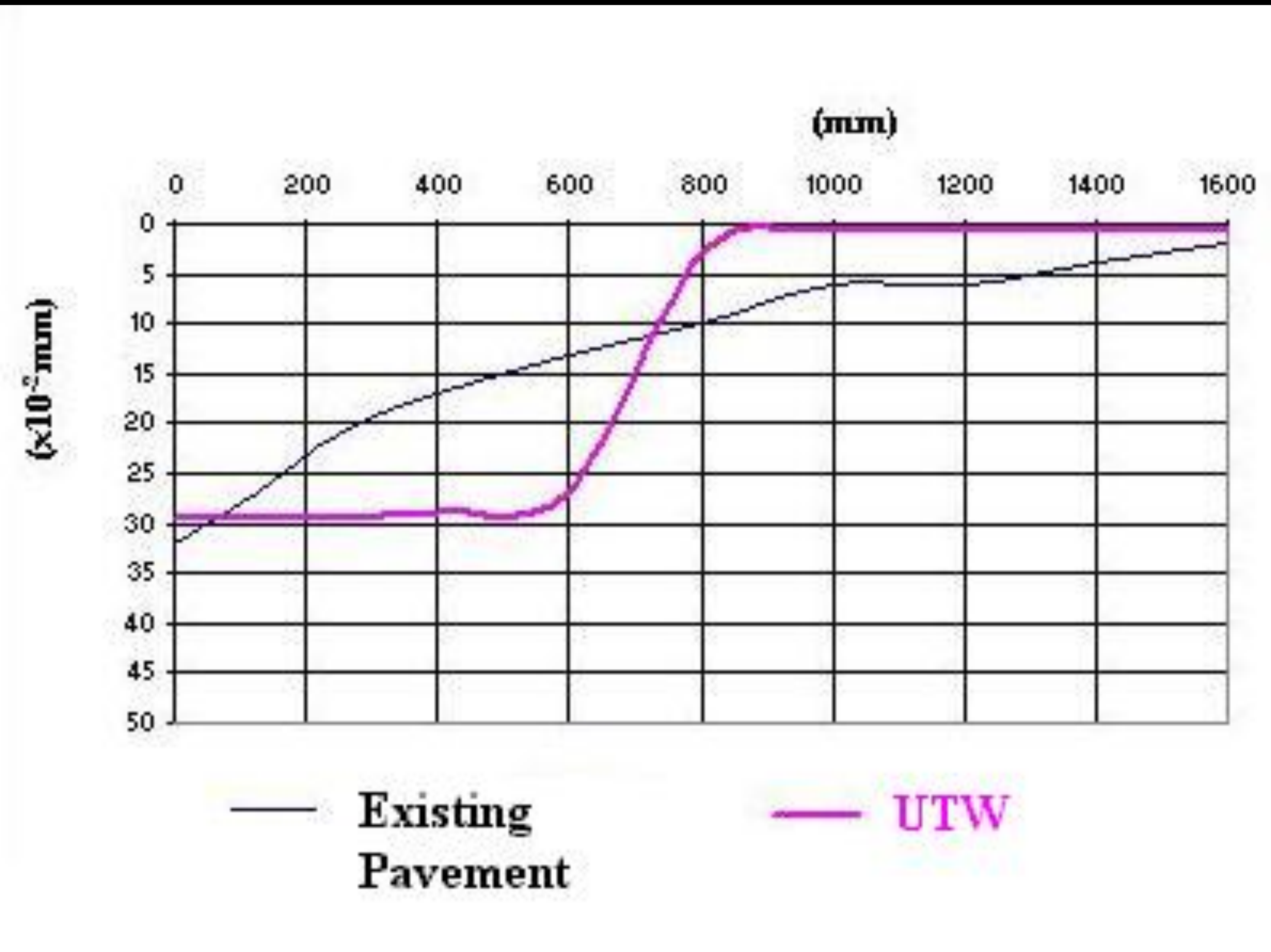
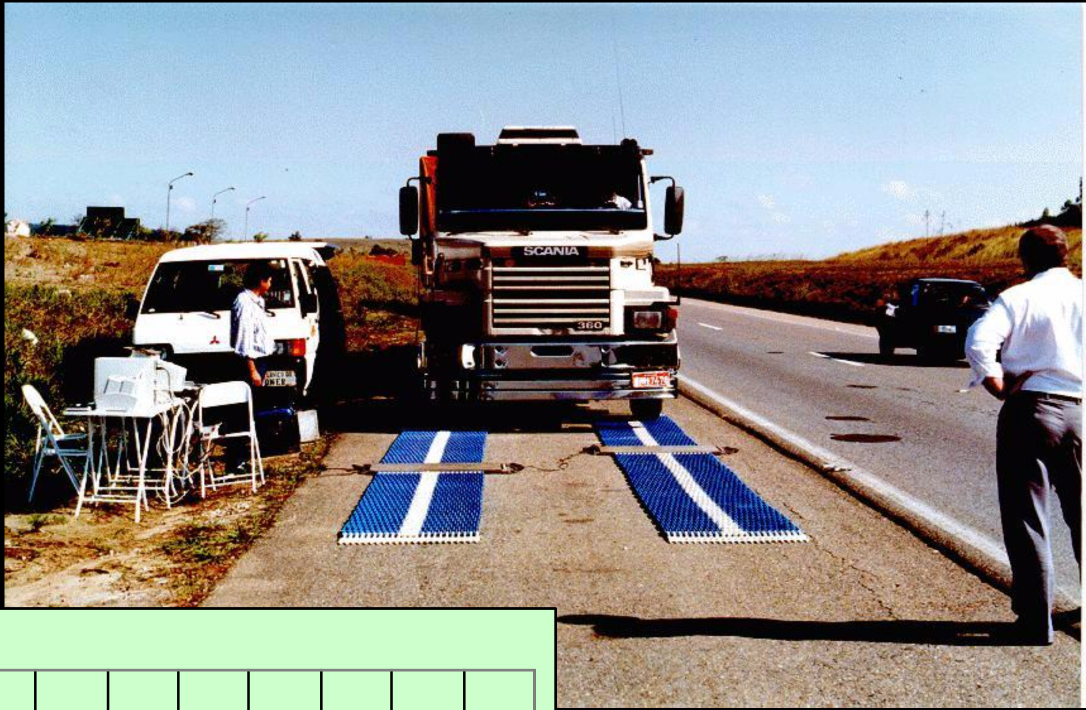
Monitoring the Experimental UTW



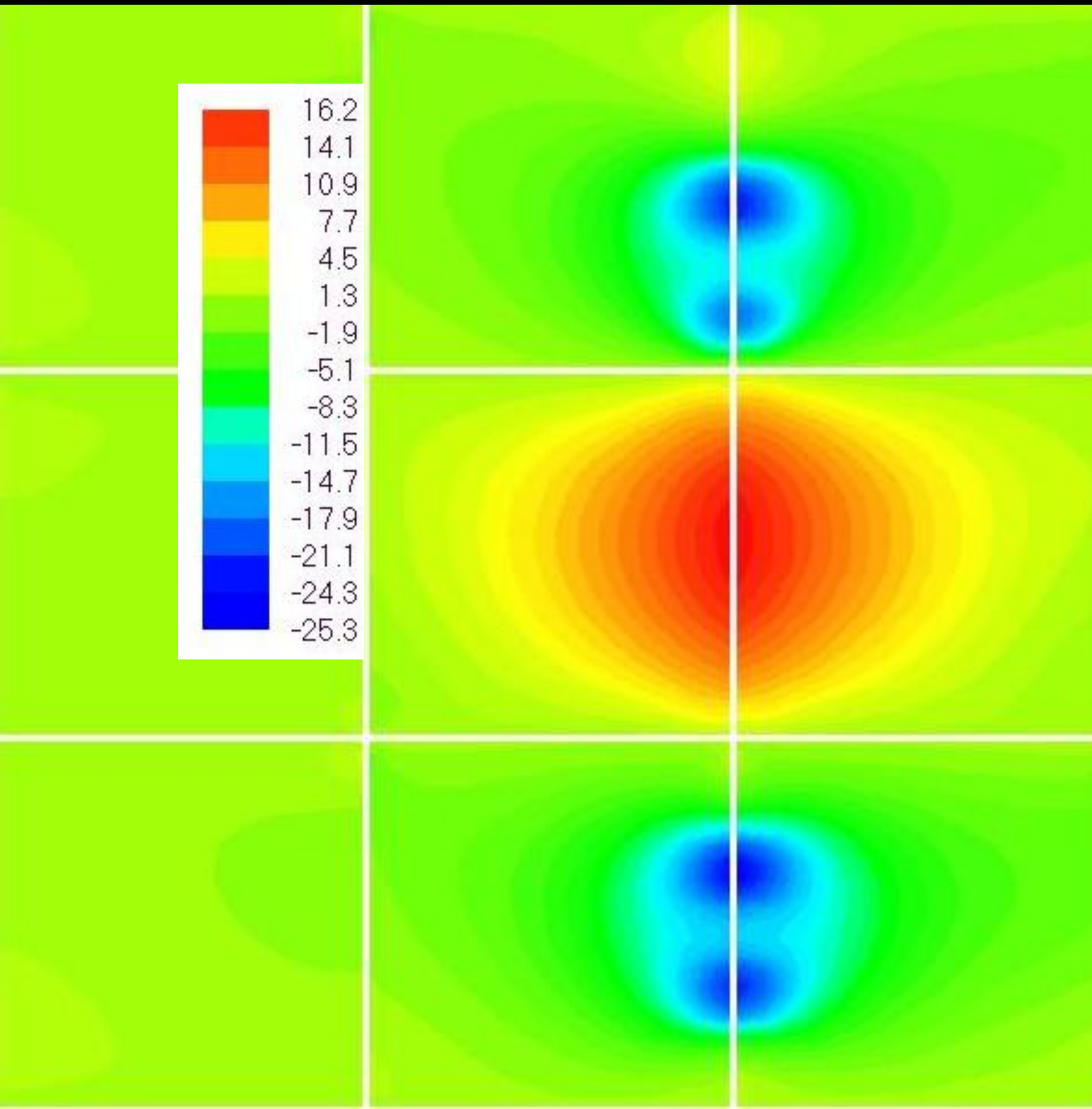
No load transfer across joints

Monitoring the Experimental UTW

Weight in motion



Predicting Flexural Stresses on UTW



FEM

Program ISLAB 2000

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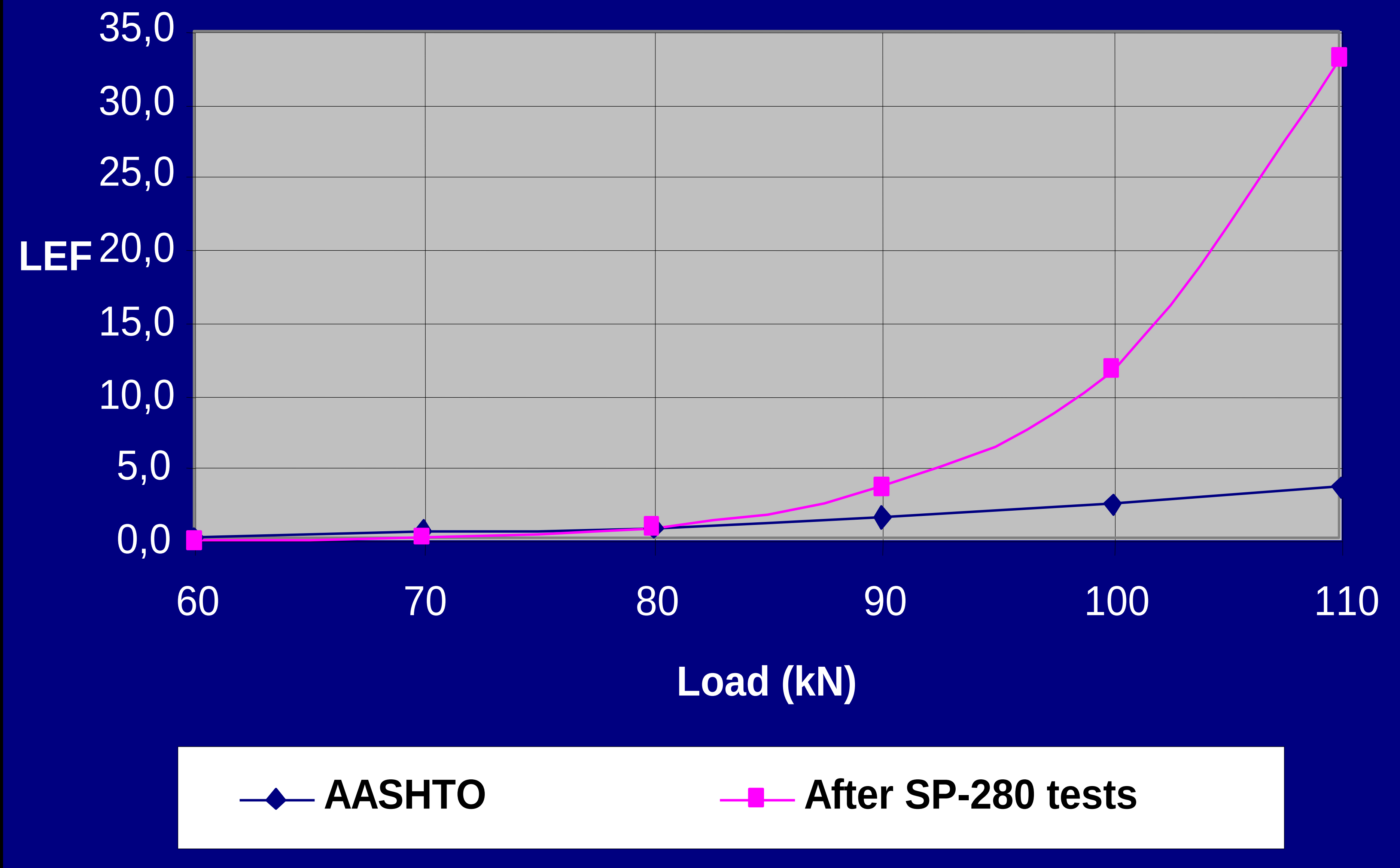
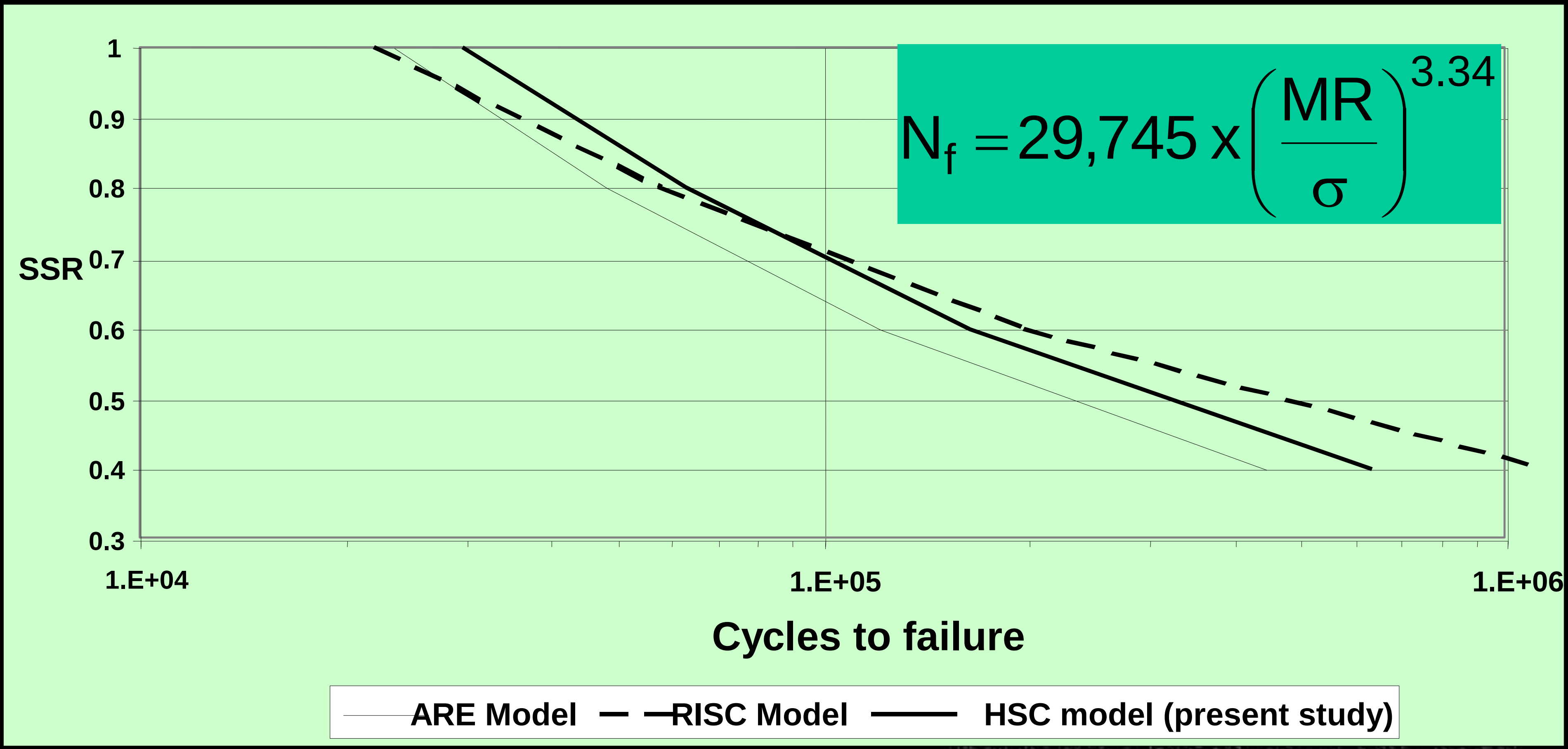
Monitoring the Experimental UTW

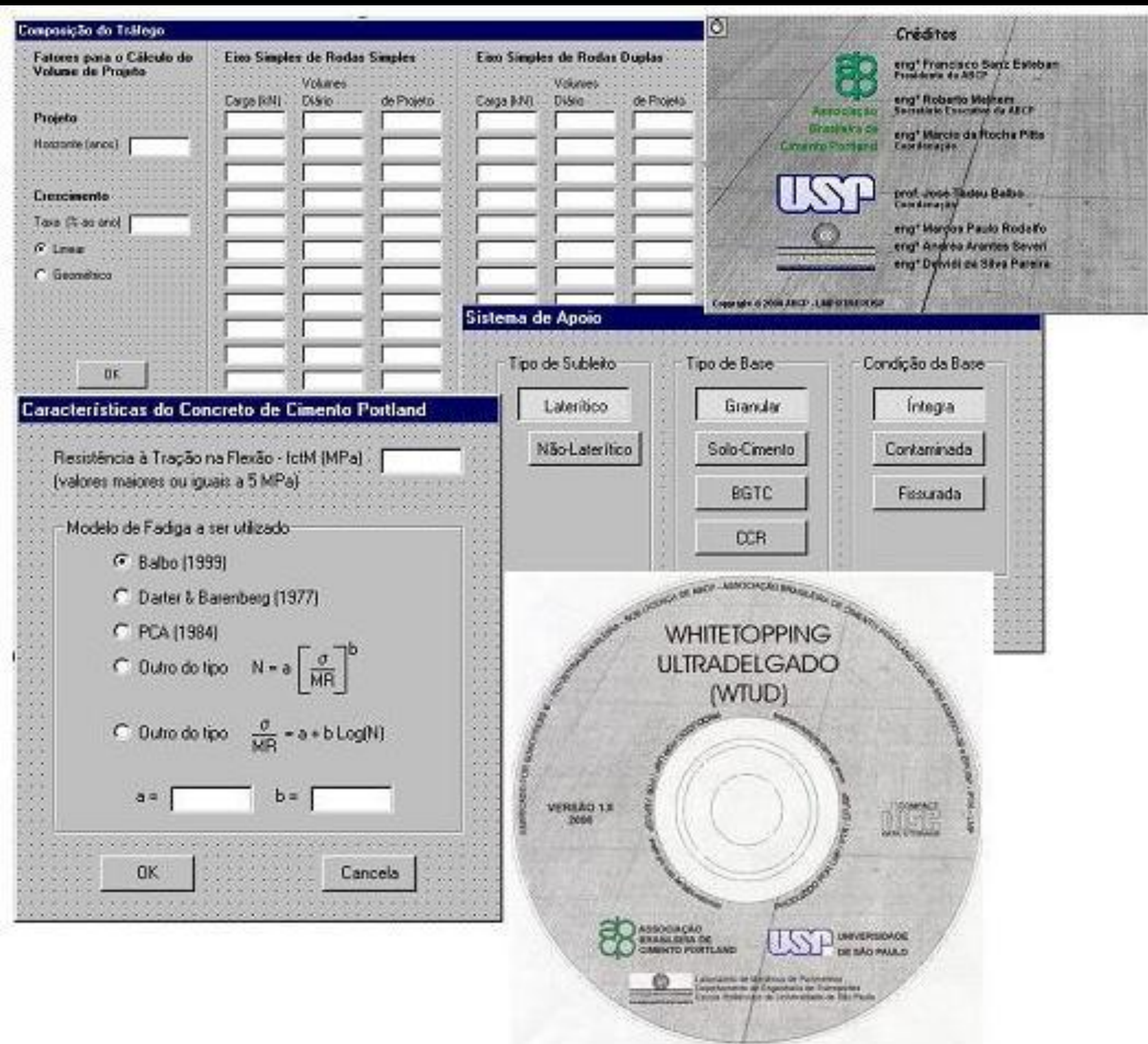


Main Findings



Main Findings

Working joint to Brazilian Cement Industry



Software

WTUD

(2000)

Available at

www.ptr.poli.usp.br/lmp

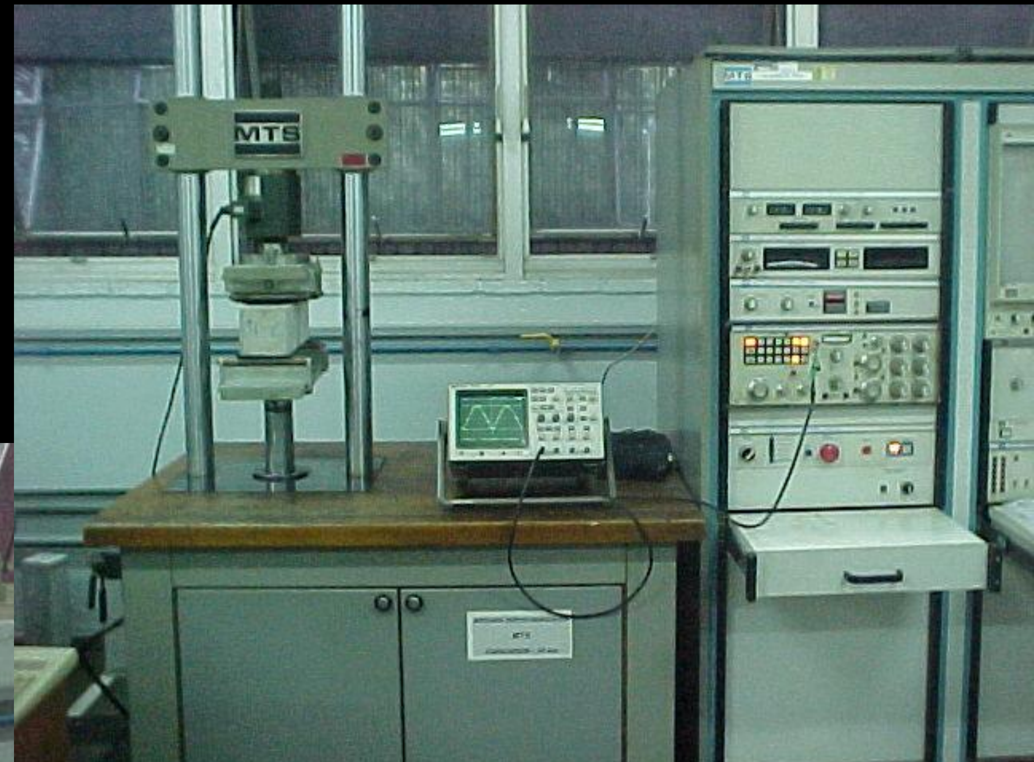
(free download)

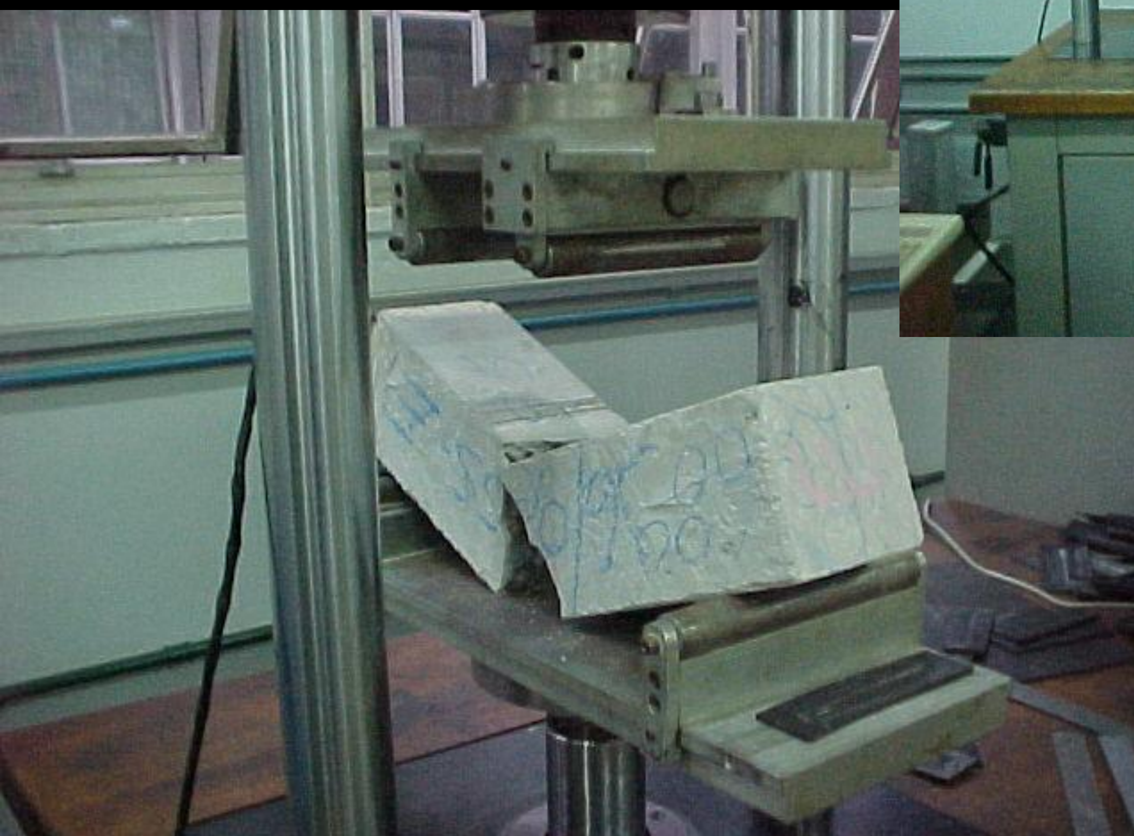
Fatigue experimental study for the HSC

The same HSC of UTW field experiment

Constant stresses test

Variable stress tests





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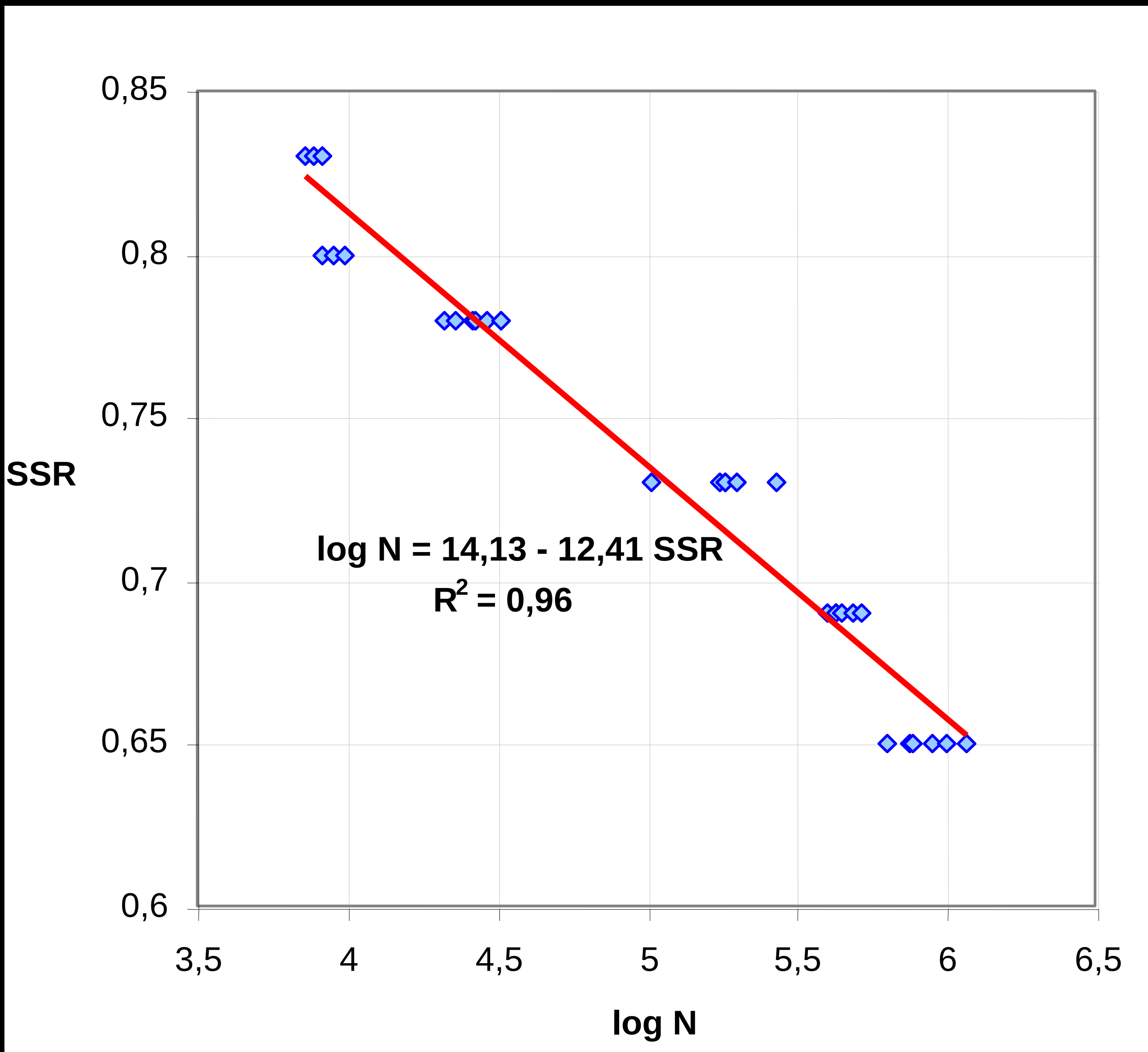
Fatigue experimental study for the HSC



Results for constant stresses

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Fatigue experimental study for the HSC

σ (MPa)	SSR	Total cycles to failure					
		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
2.32	0.39	52,674	52,674	52,674	52,674	52,674	52.674
2.66	0.44	65,172	65,172	65,172	65,172	65,172	65.172
2.96	0.49	52,638	52,638	52,638	52,638	52,638	52.638
3.28	0.55	53,010	53,010	53,010	53,010	53,010	53.010
3.54	0.59	25,452	25,452	25,452	25,452	25,452	25.452
3.72	0.62	103,830	103,830	103,830	103,830	103,830	103.830
3.90	0.65	242,820	242,820	242,820	242,820	242,820	242.820
4.10	0.68	157,122	157,122	157,122	157,122	157,122	157.122
4.26	0.71	43,530	45,924	45,924	45,924	45,924	45.924
4.42	0.74	9,250	9,990	10,200	11,070	11,070	11.070
4.56	0.76	7,000	7,000	7,000	7,130	8,394	8.394
4.68	0.78	5,850	5,850	5,850	5,850	6,966	6.966
4.78	0.80	2,400	2,400	2,400	2,400	2,856	2.856
4.85	0.81	1,250	1,250	1,250	1,250	1,420	1.450
Total		821,998	825,132	825,342	826,342	829,348	829,378

Variable stresses simulated according to field history events predicted by ILSL2

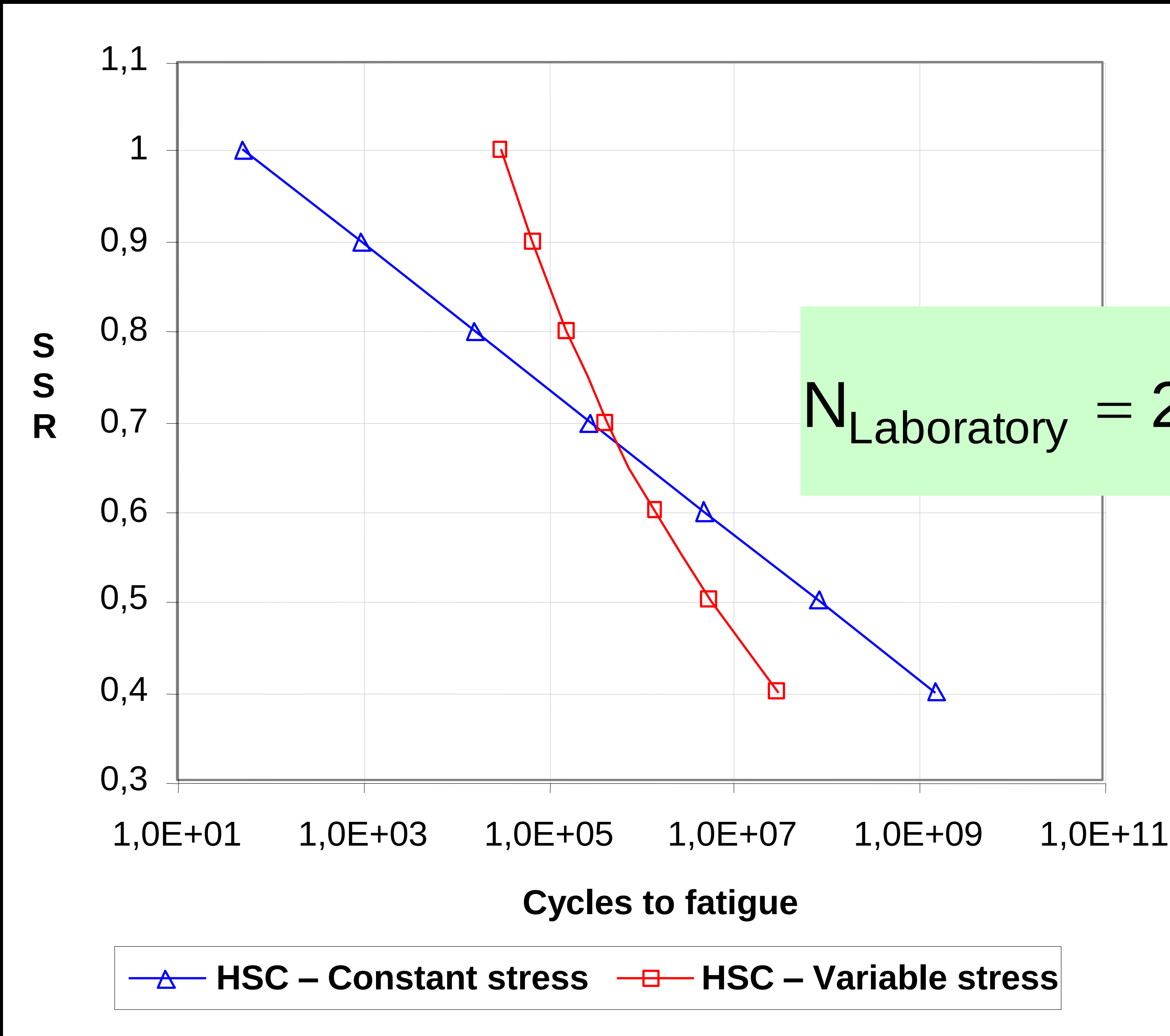
Fatigue experimental study for the HSC

$$\frac{N_{1,p}}{N_{1,adm}} + \frac{N_{2,p}}{N_{2,adm}} + \ldots\ldots\ldots\ldots + \frac{N_{n,p}}{N_{n,adm}} = 1$$

$$N_{i,adm} = k\left(\frac{1}{SSR}\right)^{c}$$

$$\frac{N_{1,p}}{k.\left(\frac{f_{ct,f}}{\sigma_1}\right)^{c}} + \frac{N_{2,p}}{k.\left(\frac{f_{ct,f}}{\sigma_2}\right)^{c}} + \ldots\ldots\ldots + \frac{N_{n,p}}{k.\left(\frac{f_{ct,f}}{\sigma_n}\right)^{c}} = 1$$

Fatigue experimental study for the HSC



$$N_{Laboratory} = 29.745.\left(\frac{1}{RT}\right)^{7,54}$$

e Mecânica de Pavimentos
usp.br

Fatigue experimental study for the HSC

$$N_{Laboratory} = 29,745 \text{ x} \left(\frac{1}{SSR} \right)^{7,54}$$

$$N_{Field} = \left(\frac{1}{SSR} \right)^{-4,20231} . N_{Laboratory}$$

$$N_f = 29,745 \text{ x} \left(\frac{MR}{\sigma} \right)^{3.34}$$

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1999 UTW

USP Campus

USP and FAPESP

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Research Motivations and Targets

Unsucessful first experiment (1997)

Studying Alternative for Buses Corridors

Rule of thin layers of existing HMA

Effects of Tropical Environment

Understanding of HSC for pavements

Construction of the Experimental UTW

UTW Design:

Section A : 0.6 x 0.6 m (4.8 m)
Section B : 1.0 x 1.0 m (5.0 m)
Thickness : 95 mm

Existing pavement structures:

HMA : 50 mm (3,000 MPa)
Hydraulic Macadam base : 100 mm (120 MPa)
Lateritic Clay soil: (90 MPa)

Construction of the Experimental UTW

Site:

Bus stop within the USP campus

ADT

110 urban buses + 10 trucks + 500 cars

Construction steps:

Milling HMA – 10/31/1999

Instrumentation- 11/01/1999

Concrete laying – 11/02/1999

Opening to traffic – 11/08/1999

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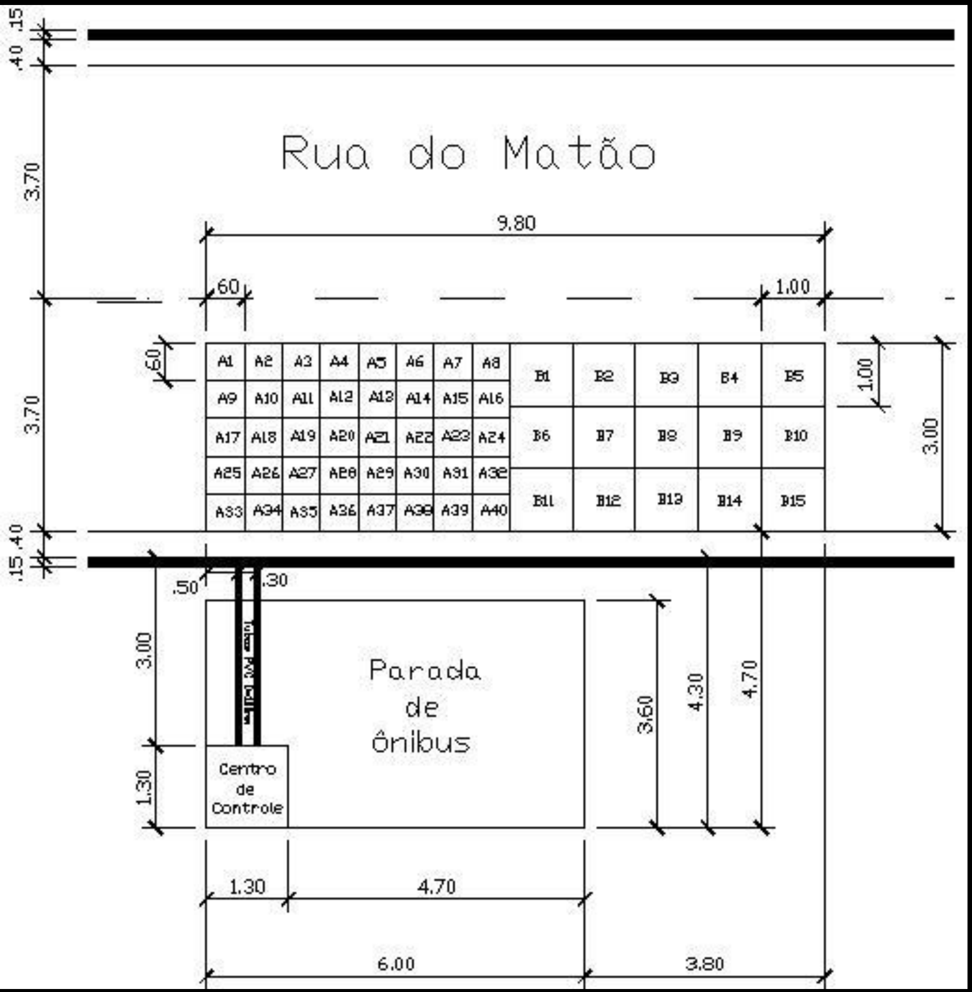
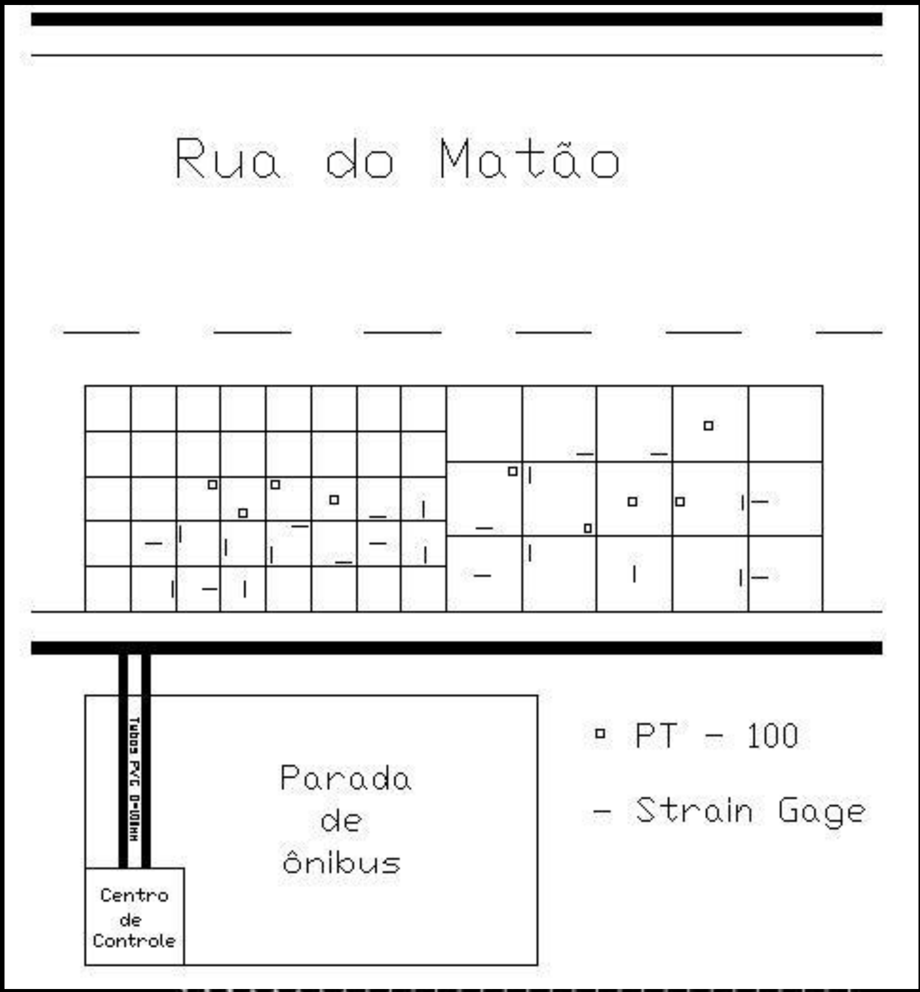
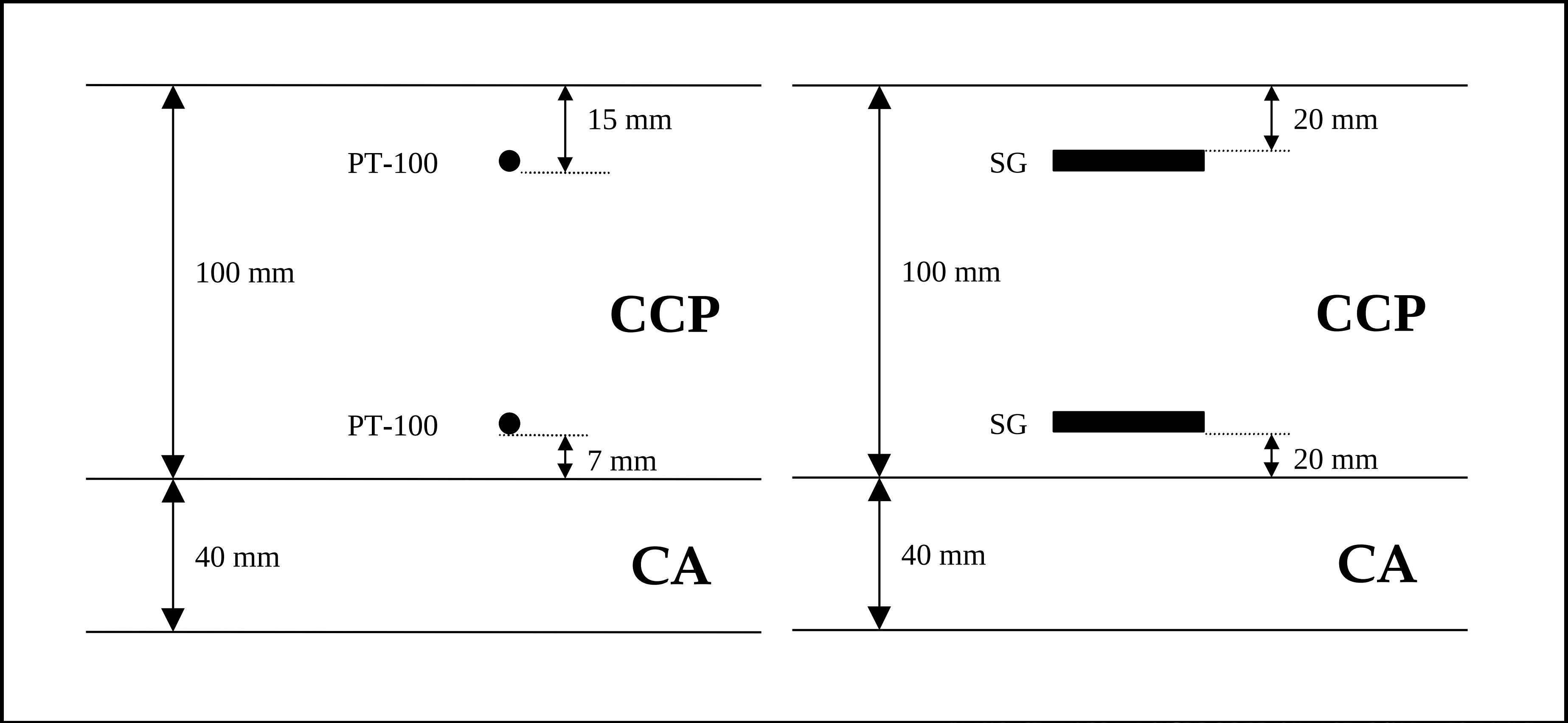
Instrumentation for UTW - Details





Instrumentation for UTW - Details



Number of devices: 48 *strain-gages* and 18 PT-100

Test Pavement Construction Details

Fast Setting Cement (kg/cm)	476
Silica Fume (kg/cm)	28.5
Sand (kg/cm)	642
Crushed stone diam. max. 19 mm (kg/cm)	1,029
Water/(cement+silica) ratio	0.40
Plasticizer (L/cm)	1.43
Super-plasticizer (L/cm)	2.38
Slump test at field (mm)	140
Flexural strength at 7 days (MPa)	7.0
Flexural strength at 28 days (MPa)	7.1
Modulus of elasticity at 28 days (MPa)	38,000

Test Pavement Construction Details

Construction site

Test Pavement Construction Details

The existing HMA (10 mm rut depth)

Test Pavement Construction Details

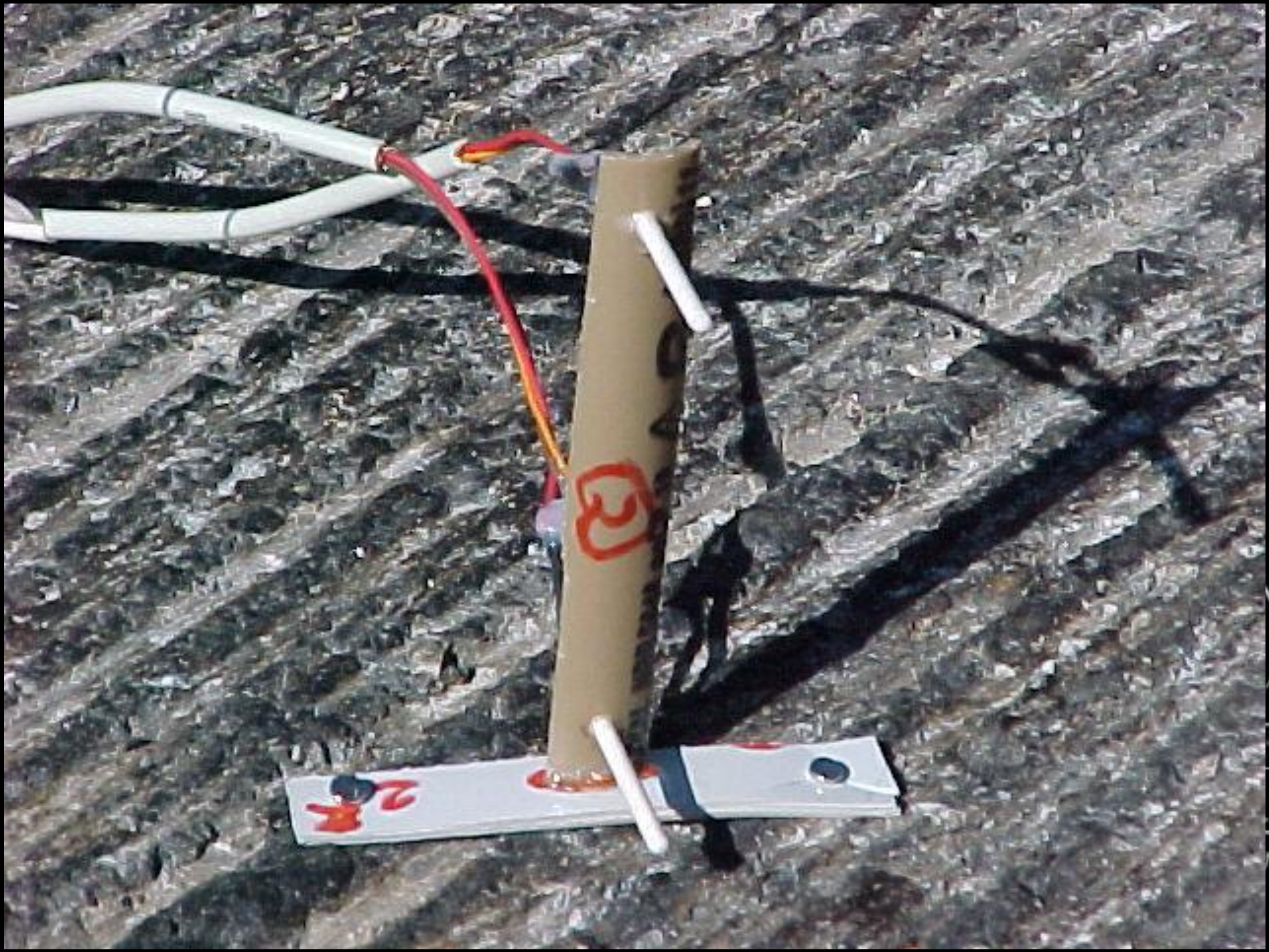
Milling and washing the HMA

Test Pavement Construction Details

Strain-gages instalation

Test Pavement Construction Details

Thermal-resistors fixing



Test Pavement Construction Details

Test area ready to receive the Portland concrete

Test Pavement Construction Details

Burring strain-gages and thermocouples

Test Pavement Construction Details

Finishing HSC surface

Test Pavement Construction Details

Curing the HSC (3 first days – burlap and water 4 times a day)

Test Pavement Construction Details

Finishing the HMA lateral slopes (day 4)

Test Pavement Construction Details

Openned to traffic 8 days latter

Test Pavement Construction Details

Shrinkage opening after joint sawcut

Temperatures & Gradients

	Maximum Top Temp. (ºC)				Minimum Top Temp. (ºC)			
	autumn	winter	spring	summer	autumn	winter	spring	summer
Max.	29.7	25.4	40.0	48.3	14.3	15.2	20.1	22.8
Min.	26.5	17.3	25.2	38.9	10.2	5.4	16.5	20.3
Average	28.0	22.4	33.3	43.1	12.4	11.1	17.9	21.6

	Maximum DT (ºC)				Minimum DT (ºC)			
	autumn	winter	spring	summer	autumn	winter	spring	summer
Max.	8.4	7.8	9.4	11.7	-1.3	-1.1	-1.7	-1.9
Min.	5.4	2.2	0.4	7.6	-3.1	-2.4	-4.2	-3.6
Average	7.4	5.6	6.1	9.6	-2.1	-1.8	-2.8	-2.4

Temperatures & Gradients

Maximal Bottom Temperatures (^{o}C)
-interface UTW-HMA-

Season	Daytime	Nighttime
Fall	20.6	14.5
Winter	16.8	12.9
Spring	27.2	20.7
Summer	33.5	24.0

Concrete keeps asphalt cool!

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Temperatures & Gradients

Season	DT (^{o}C)	DT/t (^{o}C/mm)
	Daytime Gradients	
Autumn	7.4	0.115
Winter	5.6	0.10
Spring	6.1	0.129
Summer	9.6	0.160
	Nighttime	
Autumn	-3.1	-0.042
Winter	-2.4	-0.033
Spring	-4.2	-0.056
Summer	-3.6	-0.049

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Temperatures & Gradients
Ranges for Thermal Differentials in time %

Range for DT	Aut	Win	Spr	Sum	Total
Less than –6 ºC	0.0	0.0	0.2	0.0	0.1
from –6 to –3 ºC	1.1	0.8	4.1	1.0	1.9
from –3 to 0 ºC	49.2	49.7	58.9	59.5	53.3
from 0 to 3 ºC	40.0	37.7	18.9	18.7	30.5
from 3 to 6 ºC	7.3	6.0	9.4	10.8	7.7
from 6 to 9 ºC	2.4	4.6	5.9	7.8	5.0
More than 9 ºC	0.0	1.2	2.6	2.1	1.6

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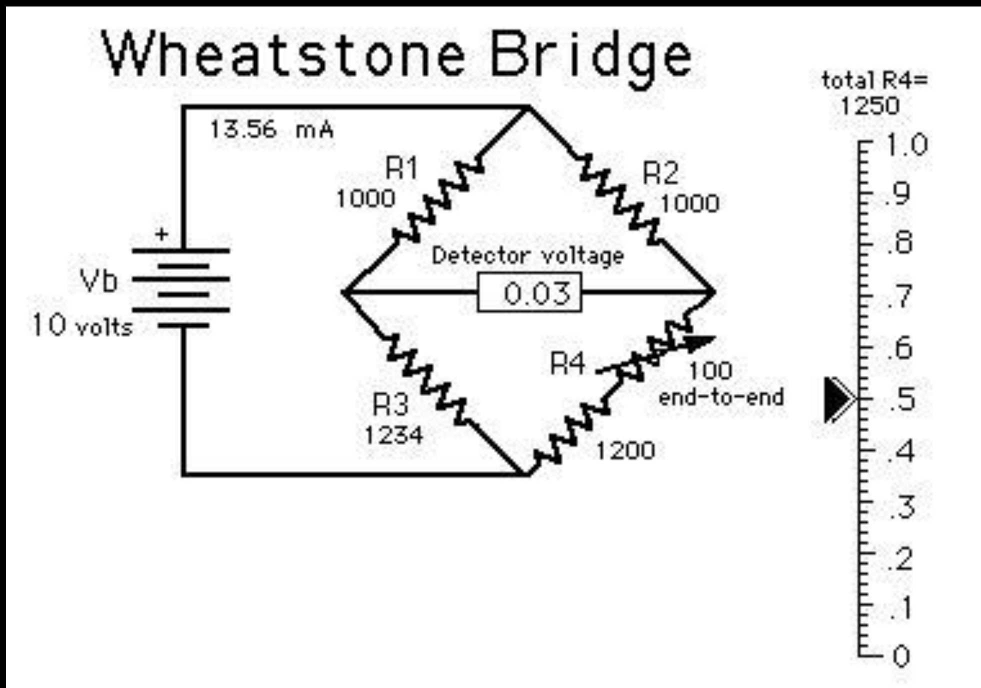
Temperatures & Gradients

Measurement of Strains : How do it works ?



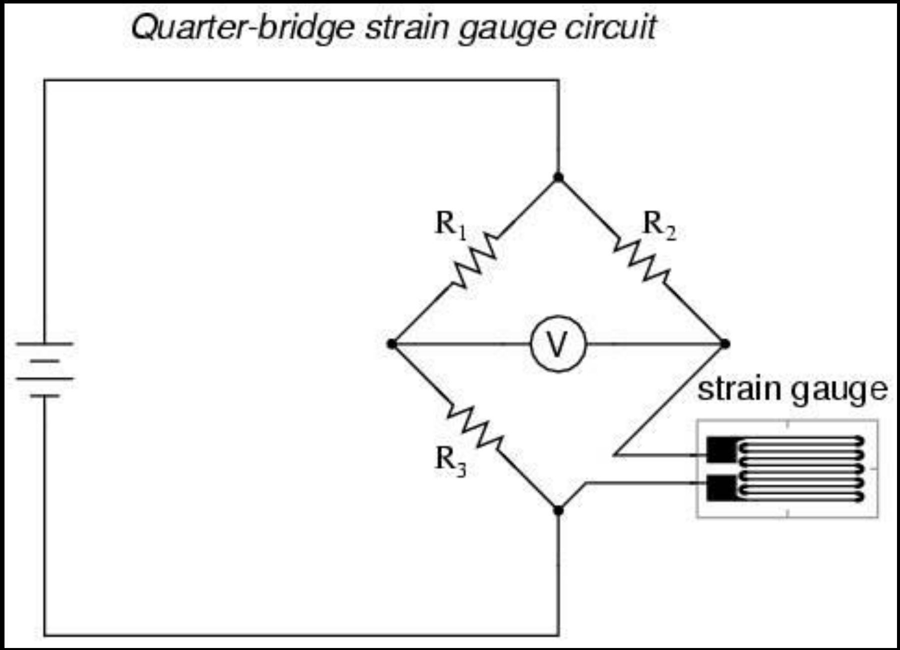
El puente de Wheatstone es un circuito eléctrico para la comparación precisa de las resistencias. Sir Charles Wheatstone es famoso de este dispositivo, pero nunca afirmó haber inventado - sin embargo, hizo más que nadie para inventar usos para ella, cuando "encontró" la descripción del dispositivo en 1843. La primera descripción del puente era por Samuel Hunter Christie (1784-1865) en 1833.

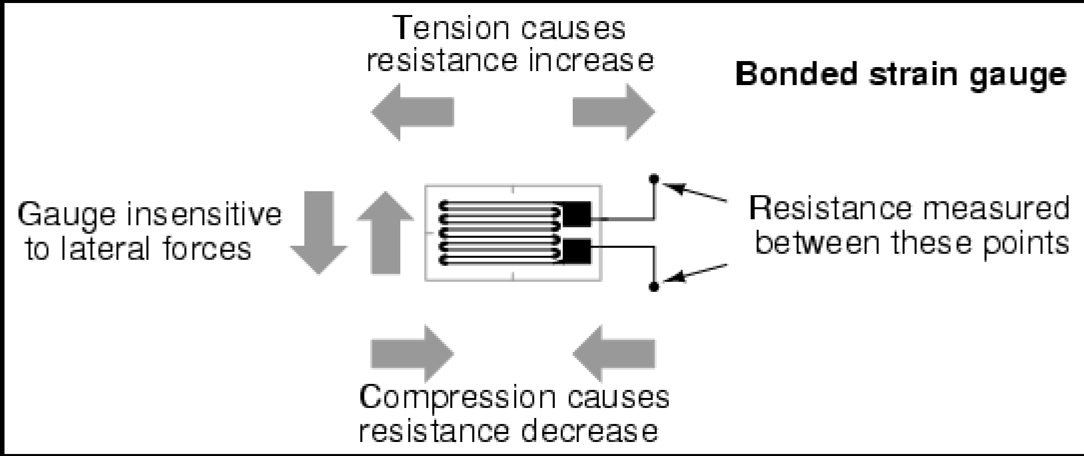
El puente de Wheatstone es muy adecuada también para la medición de pequeños cambios de una resistencia y, por lo tanto, también es adecuado para medir el cambio de la resistencia en un medidor de deformación.

Temperatures & Gradients

Measurement of Strains : How do it works ?

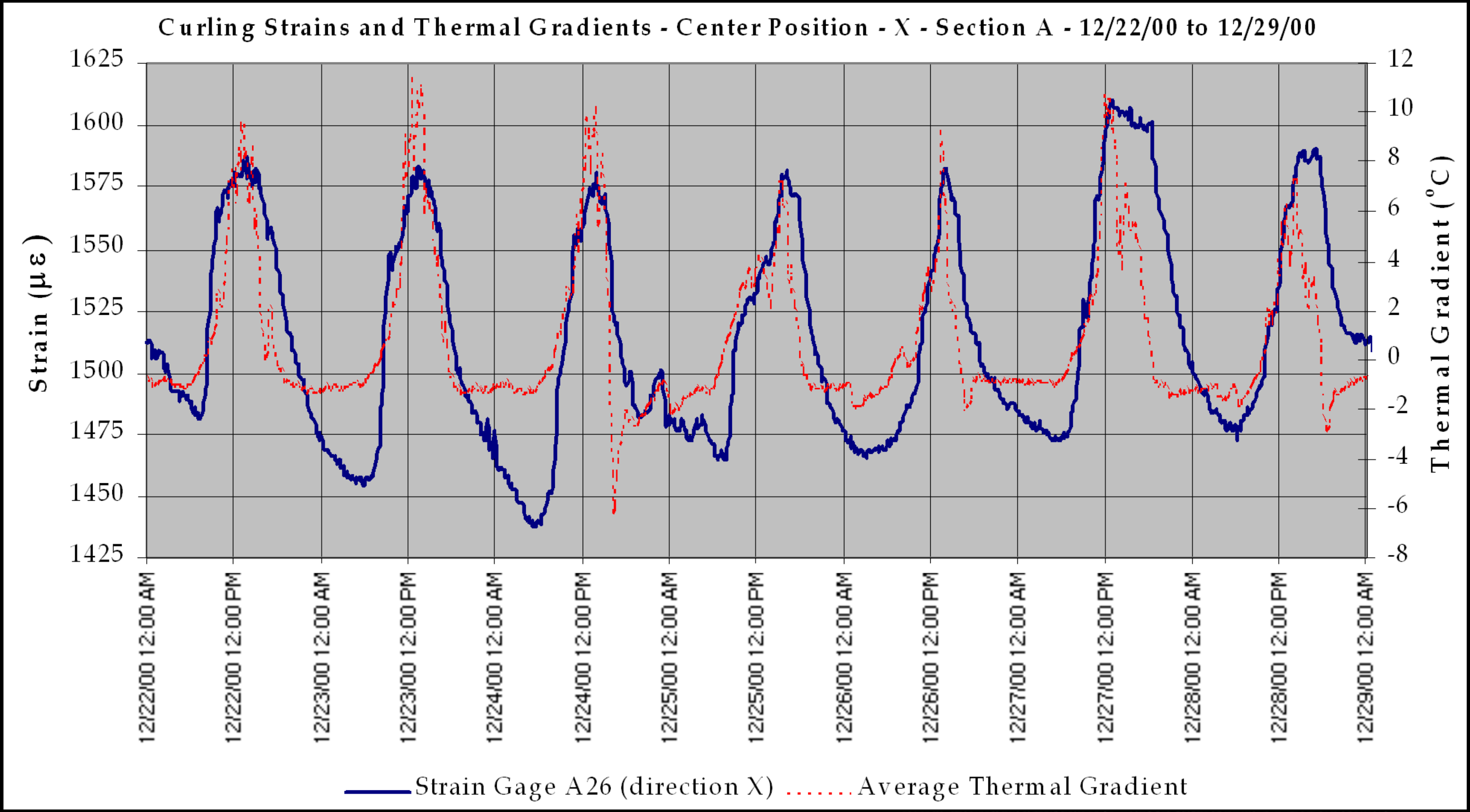
Strain Gauge





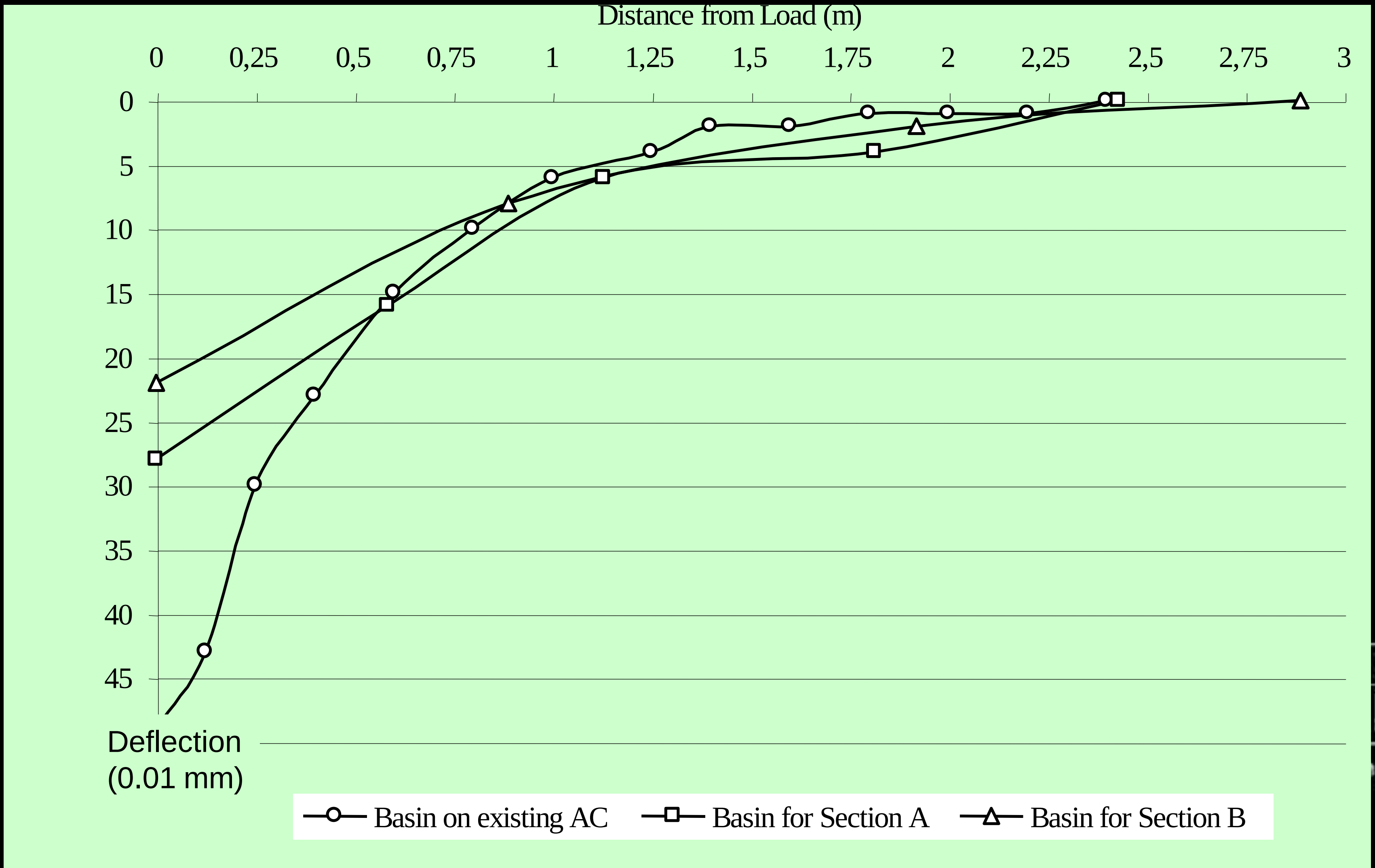
Si una tira de metal conductor se estira, se volverá más delgada y más larga, tanto los cambios resultantes en un aumento de la resistencia eléctrica de extremo a extremo. A la inversa, si una tira de metal conductor se coloca bajo la fuerza de compresión (sin pandeo), ampliará y acortar. Si estas tensiones se mantienen dentro del límite elástico de la banda de metal (de manera que la tira no se deforme permanentemente), la tira se puede utilizar como un elemento de medición de la fuerza física, la cantidad de fuerza aplicada deducirse de la medición de su resistencia.

Temperatures & Gradients
Strains due to thermal variations on slabs



Mechanical Responses (Static) (80 kN rear axle)

Deflection Basins



Mechanical Responses (Static)
(80 kN rear axle)

Mechanical Responses (Static)
(80 kN rear axle)

Stresses accessed through measured strains

Slab	Max. Top (MPa)	Bottom (MPa)
A 26	-2.3	1.9
B 03	-0.4	0.4
B 06	-1.4	not responding
B 12	-0.8	0.9

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Mechanical Responses (Dynamic) (50 kN front & 80 kN rear)

VHS aid for defining axles position during tests

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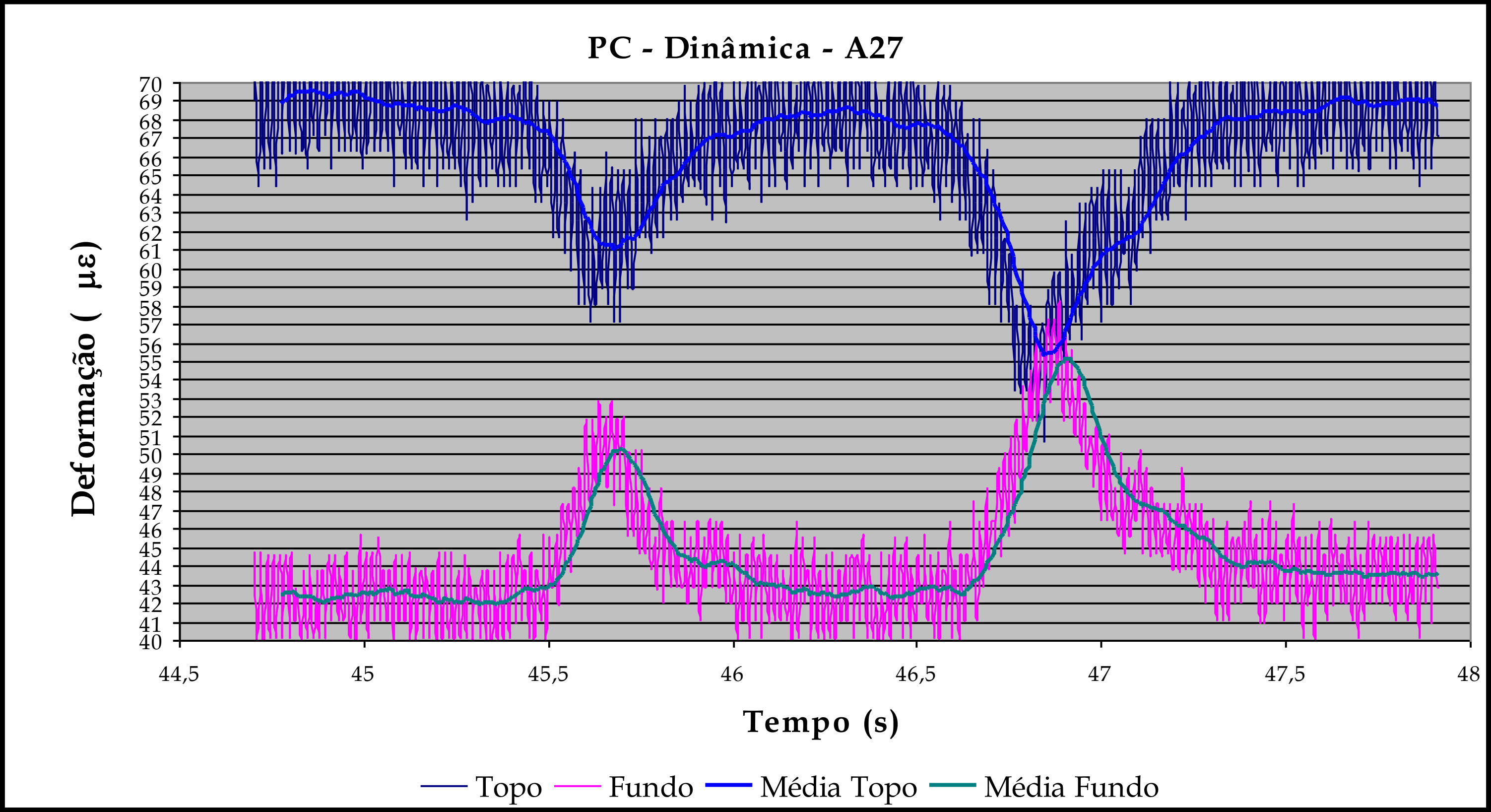
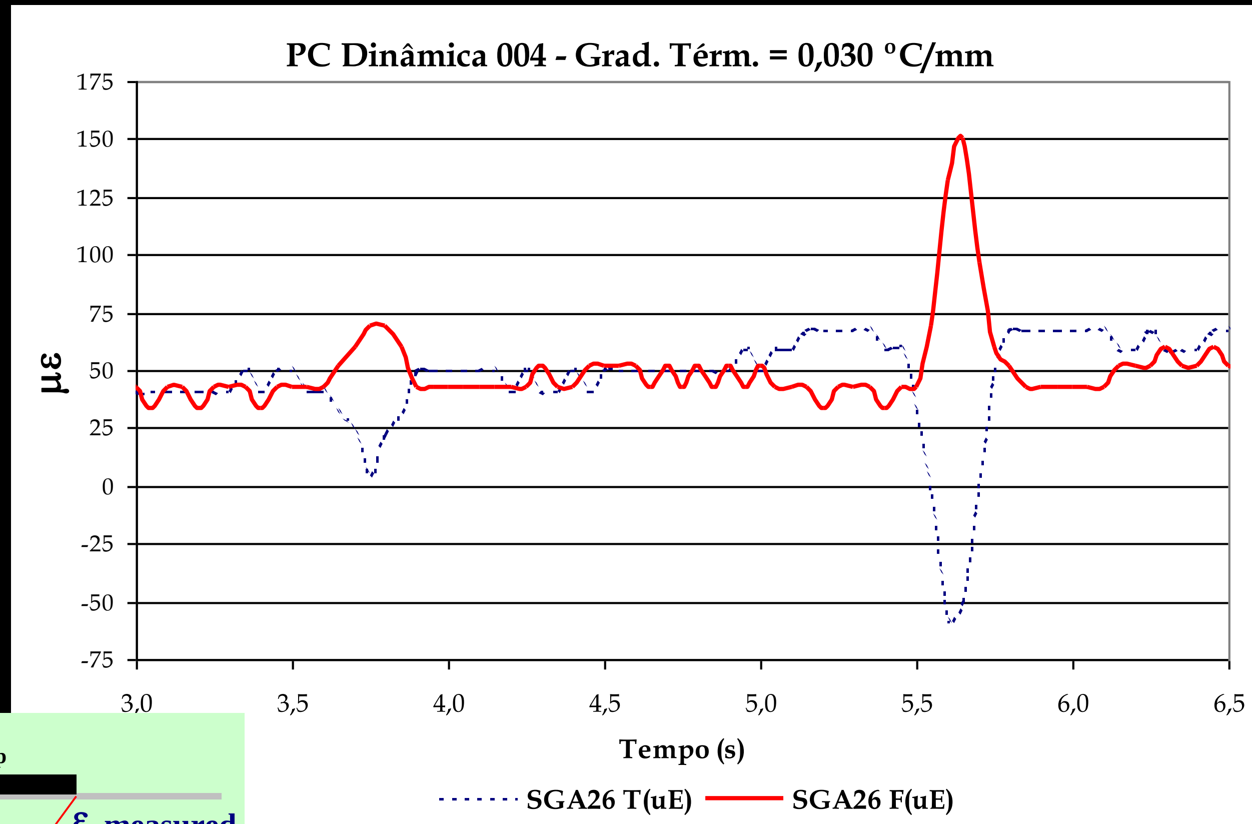
Mechanical Responses (Dynamic)
(50 kN front & 80 kN rear)

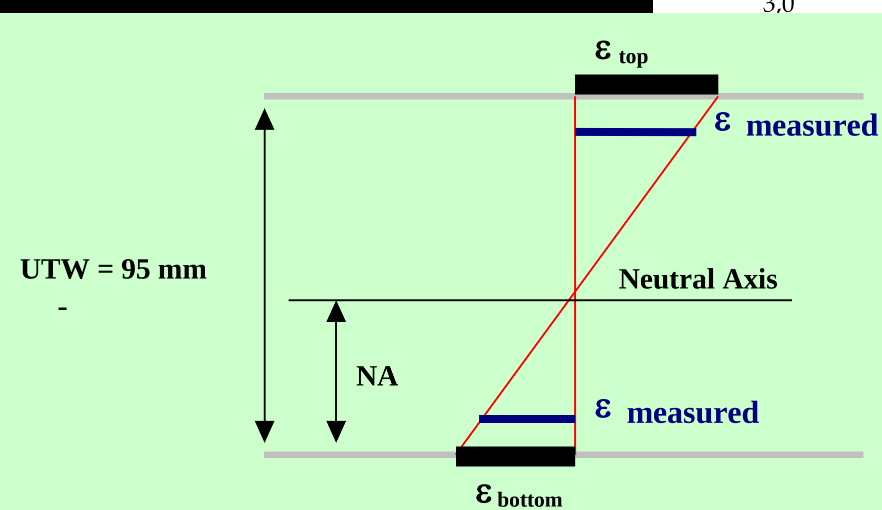


		Max. Stresses (MPa)	
		front	rear
A27	Top	0.29	0.47
	Bottom	-0.30	-0.51

Mechanical Responses (Dynamic)
(50 kN front & 80 kN rear)



Defining the neutral axis on slabs: contribution of thin asphalt layers ?

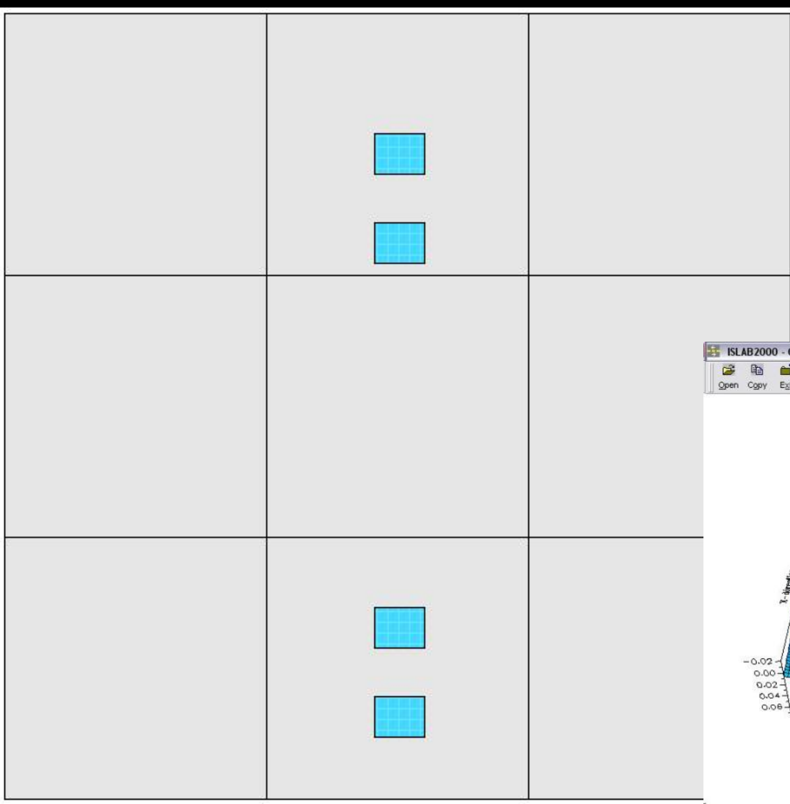


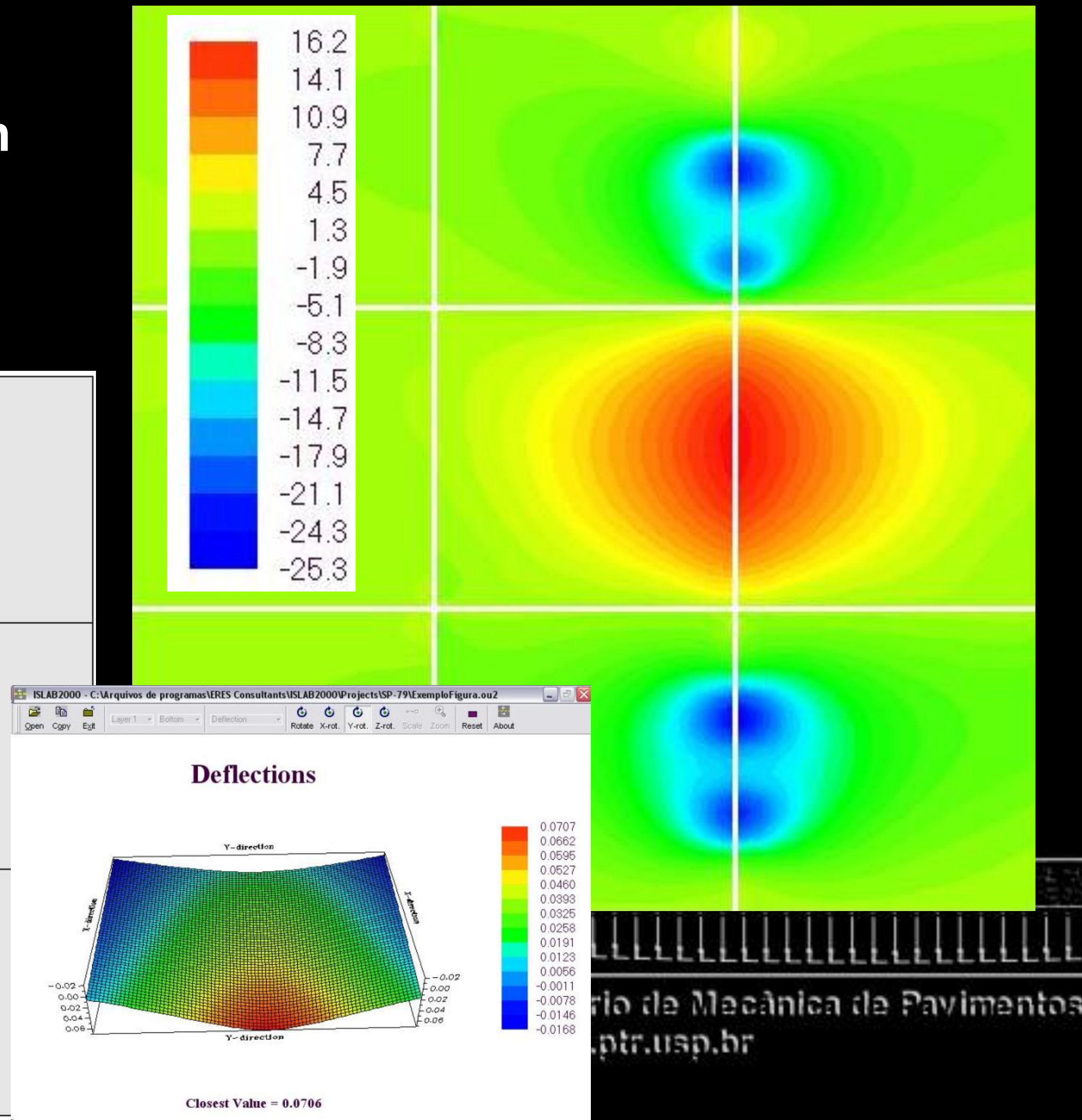
$$LN = \frac{95}{\dfrac{\left|\sigma_{topo}\right|}{\left|\sigma_{fundo}\right|} + 1}$$

Mechanical Responses (Dynamic)
(50 kN front & 80 kN rear)

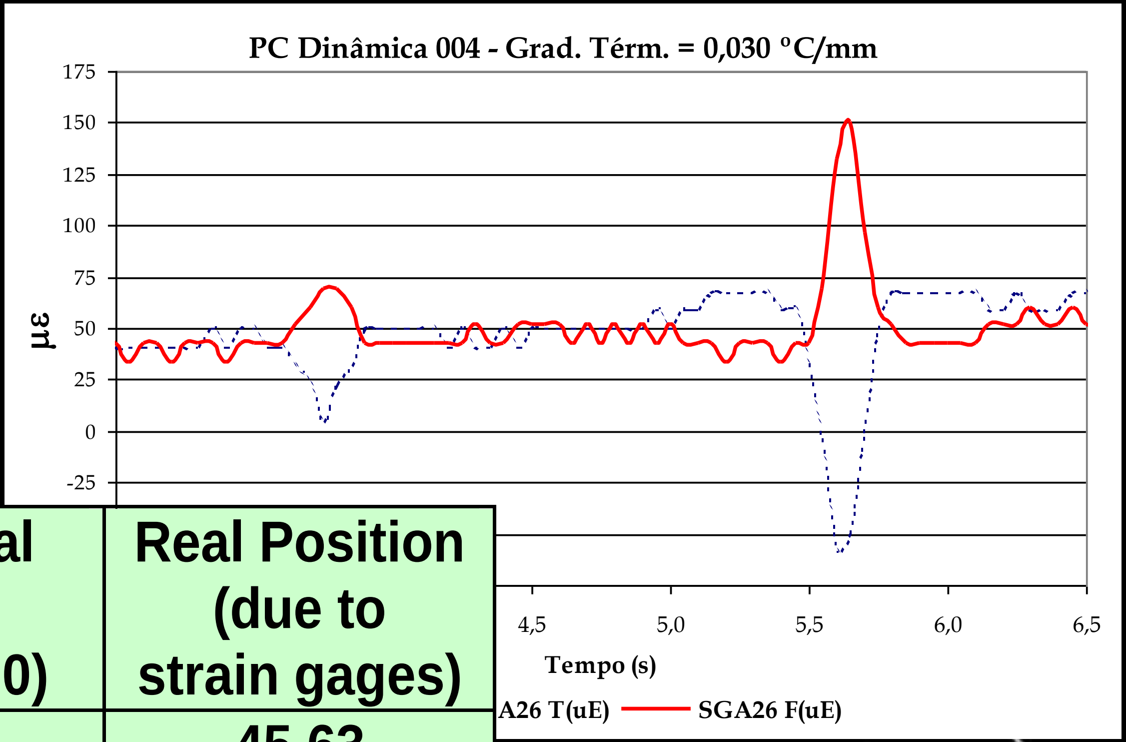
Analyzing tests with ISLAB2000

(licensed by ABCP)





Mechanical Responses (Dynamic)
(50 kN front & 80 kN rear)



Numerical and physical results says ...

NO !

Slab	Theoretical position (ISLAB2000)	Real Position (due to strain gages)
A26	43,72	45,63
A34	43,72	48,96
A36	43,72	47,79
B7	43,72	45,81
B12	43,72	47,96
All slabs	43,72	46,91

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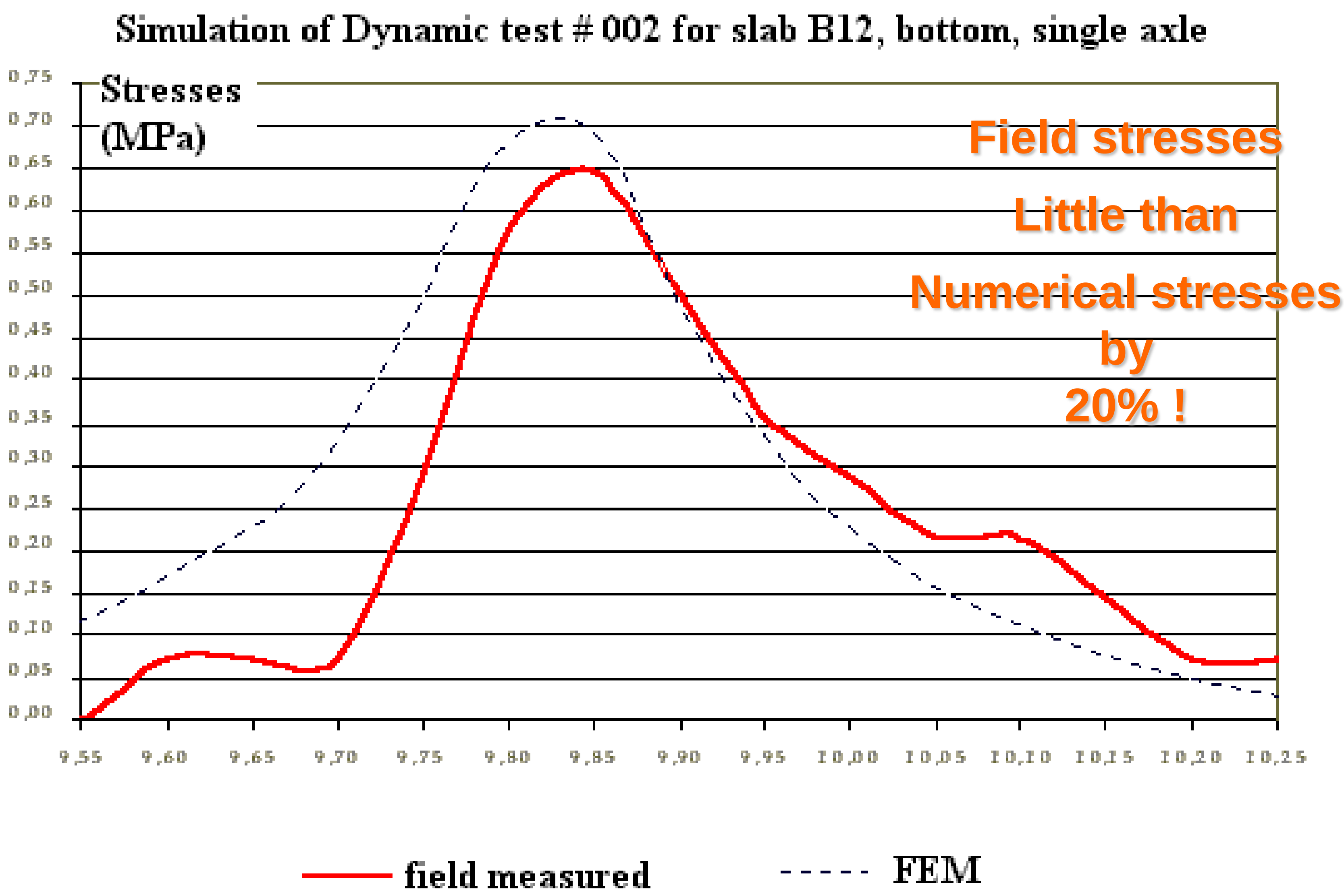
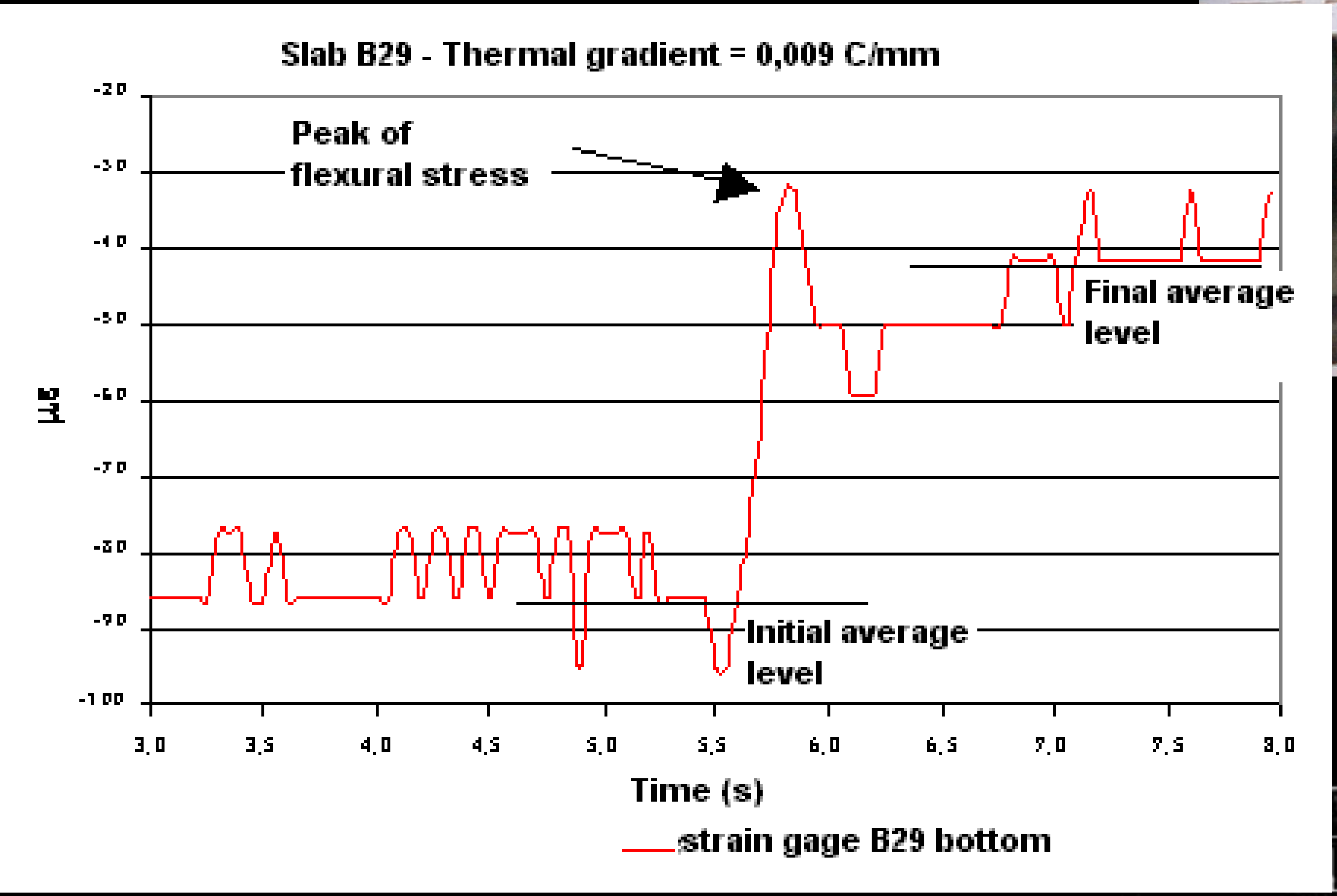
Mechanical Responses (Dynamic)
(50 kN front & 80 kN rear)



Mechanical Responses (Dynamic)
Breaking Tests



Increased from 15 to 25% de strains during tests

Pavement Performance

- up to October, 2012
  - 1,5 milion axles (buses + trucks)
- Now-a-days Pavement Condition Index (PCI)
  - Section A: ICP = 99
  - Section B: ICP = 100

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As of October, 2012

Main Conclusions

<u>About Thermal Differentials</u>

Daytime (Summer): 12.5 ºC (at 12 to 13:30)

Night (any season): -2 ºC (at 6 to 7h a.m.)

Do not alter between fall and winter nor between spring and summer

Thermal gradients are two times greater in summer

<u>Induced stresses by temperatures could be neglected for UTW</u>

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Main Conclusions

About Load Tests

Little contribution from HMA to act as composite pavement. Neutral line was not altered!

Therefore a good HSC is unavoidable

Is mandatory to keep bond at UTW / HMA interface to avoid movements

Field stresses little than predicted ones

Bus stop is a critical road session concerning breakings

Fatigue behavior of underneath HMA shall be improved as temperature is decreased along the seasons

Further Information on this Research

International Journal of Pavement Engineering, Vol. 7, No. 4, December 2006, 251–260

Taylor & Francis
Taylor & Francis Group

Theoretical and field evaluation of interaction between ultra-thin whitetopping and existing asphalt pavement

DEIVIDI DA S. PEREIRA†§, JOSÉ T. BALBO‡* and LEV KHAZANOVICH¶||

†ECOSUL Road Private Operator Co., Avenue Fernando Osório, 815, Pelotas RS 96065-000, Brazil
‡Escola Politécnica, Universidade de São Paulo, São Paulo SP 05508-900, Brazil
¶University of Minnesota, Twin cities, MN, USA

(Received 27 September 2005; revised 6 March 2006)

Ultra-thin concrete overlays or ultra-thin whitetopping (UTW), are an attractive alternative to traditional practices for the rehabilitation of asphalt pavements. However, it is widely accepted that the exiting pavement should have substantial stiffness to make a UTW a rehabilitation option. This paper re-examines this hypothesis using the performance results and structural evaluation of two experimental sections in Brazil. It is shown that structural contribution of the existing pavement is important for good performance of UTW. However, it appears that the ability of the existing pavement to ensure composite action of the individual slabs in the UTW is more important than its contribution to the flexural stiffness.

Keywords: Portland cement concrete; Ultra-thin whitetopping; Asphalt concrete; Fatigue cracking

1. Introduction

An ultra-thin whitetopping (UTW) is a Portland cement

UTW and AC layers. Milling of the top portion of the AC layer is recommended;

- The requirement for the AC layer varies between the

Tendencias Modernas

Concreto Reforzado con Fibras – CRF para Losas Delgadas

Fibras empleadas en Pavimentación en Hormigón

Acero

http://spanish.alibaba.com

Polipropileno o Sintéticas

http://www.fortaferro.com

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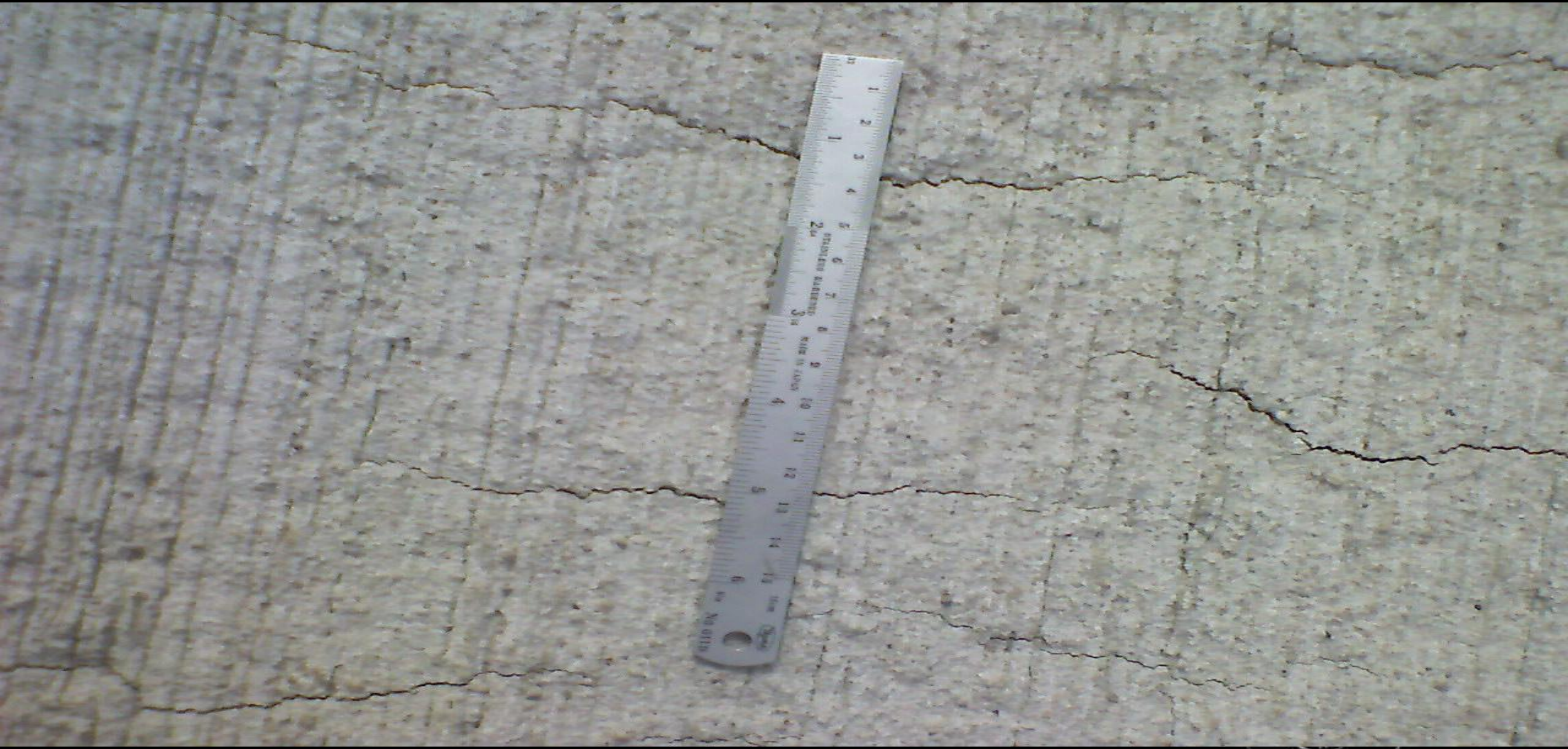
www.lmp.ptr.usp.br

Fibras son empleadas el Control de la retracción plástica



http://propriedadesdoconcreto.blogspot.com.br/

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www.lmp.ptr.usp.br

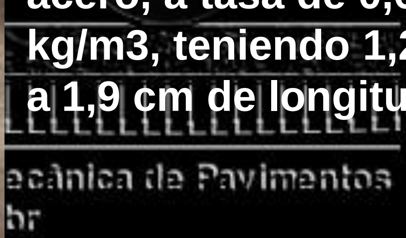
Fibras son empleadas el Control de la retracción hidráulica

Fibras de MONOFILAMENTO

FIBRAS DE MONOFILAMENTO muy finas se utilizan generalmente en una dosificación tan baja como 1,0 kg por metro cúbico de hormigón para *<u>reducir la formación de grietas por contracción plástica antes del fraguado inicial</u>*. Hecho en longitudes cortas de polipropileno son fáciles de agregar y mezclar, y resultar en un acabado de superficie invisible cercano.

http://www.dmireadymix.com

Para reducir la fisuración por retracción plástica del hormigón las fibras de monofilamento fino son usadas en conjunción con el acero, a tasa de 0,6 kg/m3, teniendo 1,25 a 1,9 cm de longitud

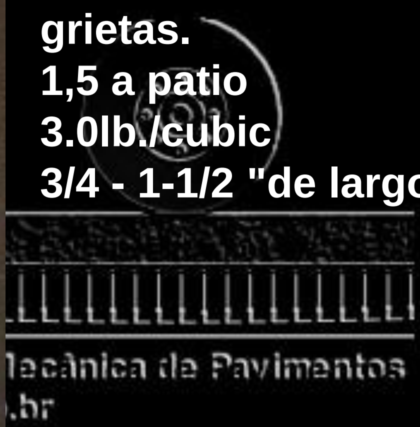


Fibras FIBRILADAS

FIBRAS FIBRILADAS o en forma de red-se utilizan generalmente en concentraciones de 0,9 a 1,8 kg/m^3 para <u>reducir el agrietamiento por contracción plástica y hidráulica</u>, y actuar como una alternativa viable a la malla de acero, en muchas aplicaciones. Hecho de polipropileno en longitudes corto a mediano.

http://www.dmireadymix.com

Reducir la contracción plástica y de la temperatura relacionada con la formación de grietas.
1,5 a patio
3.0lb./cubic
3/4 - 1-1/2 "de largo

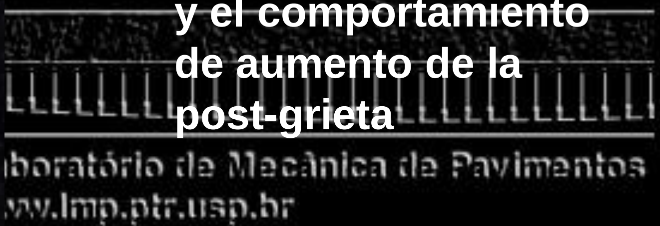


Fibras MACROSINTÉTICAS

Las MACRO-FIBRAS SINTÉTICAS representan la siguiente generación de tecnología sintética, capaz de un nivel de sustitución mucho más alto de refuerzo de acero convencional. La fibra macro maximiza cada una de las características de las fibras que contribuyen a la durabilidad a largo plazo y el control de grietas. Uso avanzado de co-polímero química y una mezcla de formas de fibra, junto con haces de trenzado y de color gris especial para asegurar el acabado superficial uniforme de mezcla y una excelente mejor de su tipo único macro-sintético puede ser utilizado en una dosis mucho más alta (3 a 4,5 kg/m^3 o más).

http://www.dmireadymix.com

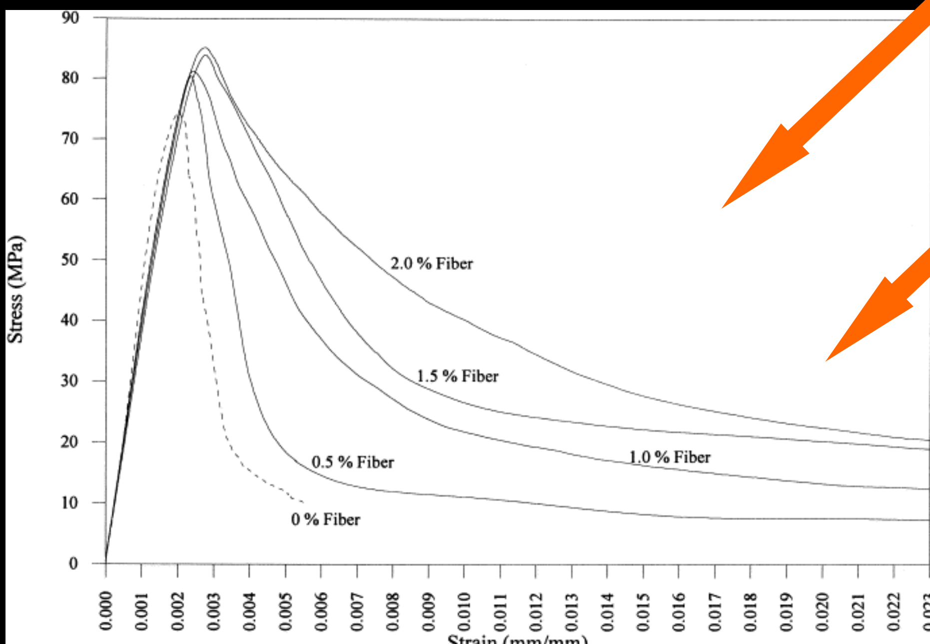
Reduce la retracción del hormigón plástico y endurecido y grietas relacionadas con la temperatura.
Añadir la tenacidad y el comportamiento de aumento de la post-grieta



Diferenciación entre los tipos de fibras

Fibras no estructurales

Fibras estructurales



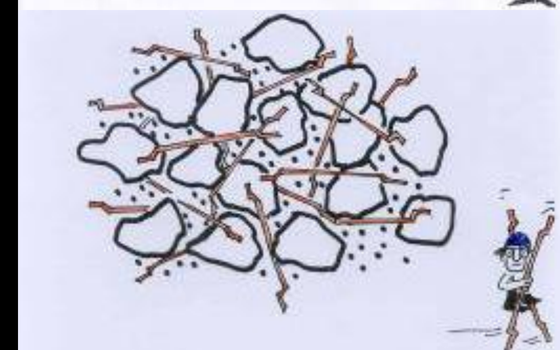
Relationship between impact energy and compression toughness energy of high-strength fiber-reinforced concrete.Materials Letters, Volume 47, Issues 4–5, February 2001, Pages 297-304
Khaled Marar, Özgür Eren, Tahir Çelik

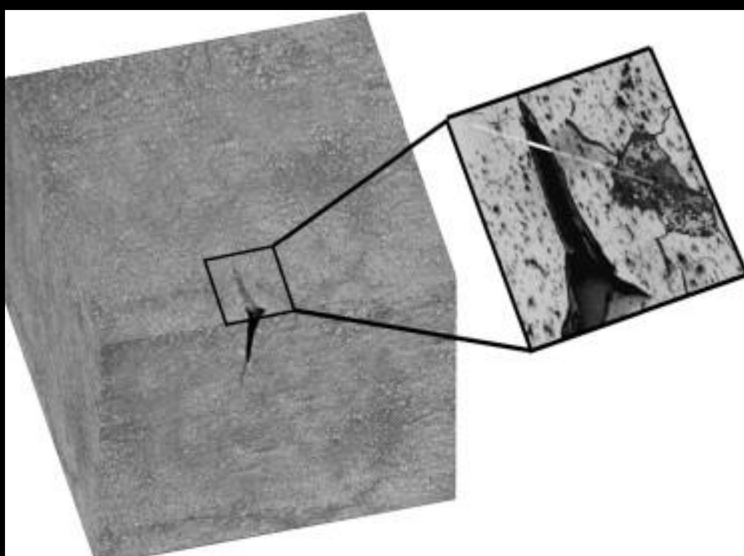
La adición de fibras provoca aumento de la ductilidad del material

Fibras de Acero :

"Coser" microfisuras

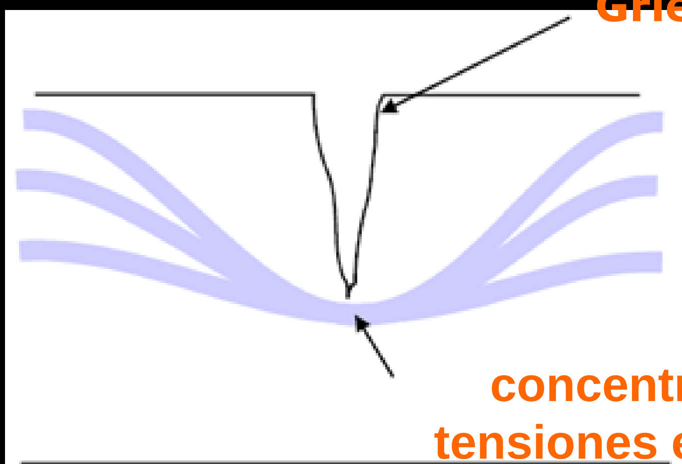
Superposición de al menos 2 agregados

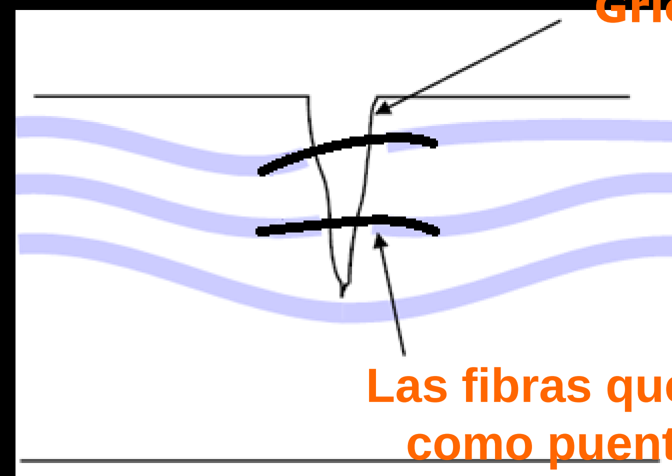




Construction and Building Materials
Volume 27, Issue 1, February 2012, Pages 73–77
The effects of polypropylene fibers on the properties
of reinforced concrete structures

La adición de macro fibras sintéticas también provoca aumento de la ductilidad del material





Moraes, A. (2011) *2nd Int. Conf. On Best Practices for Concrete Pavements*. ISCP, Florianópolis

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Restricciones para las macro fibras sintéticas

El diámetro equivalente debe ser mayor que 0,3 mm (tolerancia de +/- 50%)

La longitud no debe superar los 40 mm (con una tolerancia de +/-5%)

Módulo de elasticidad es mayor que 20.000 MPa

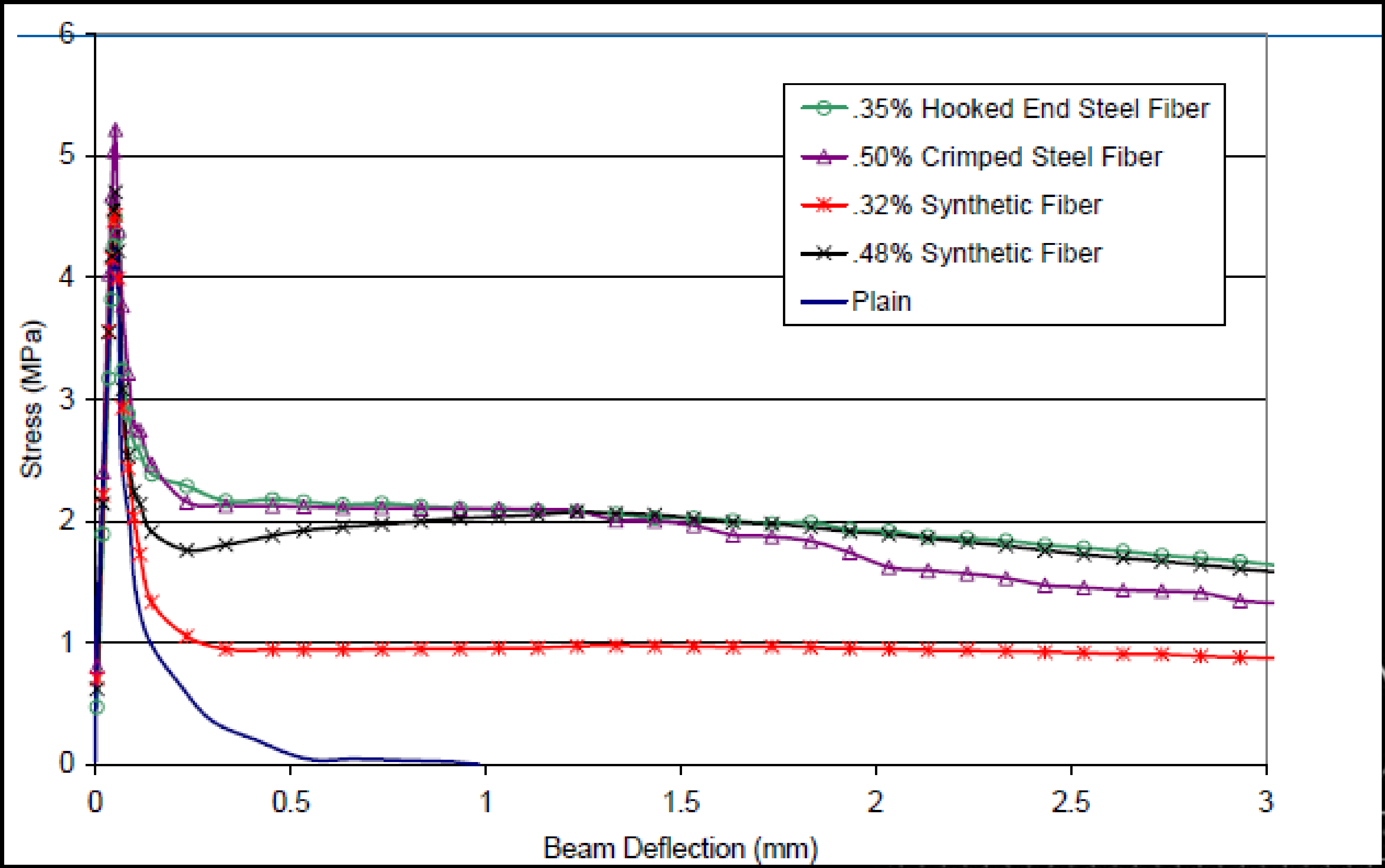
El polímero debe ser resistente a los álcalis: depende del tratamiento superficial dado por el fabricante

Forma de la fibra: sin restricciones

Propiedades térmicas: debe declarar la temperatura de transición vítrea y descomposición, y punto de reblandecimiento de ignición.

Moraes, A. (2011) *2nd Int. Conf. On Best Practices for Concrete Pavements*. ISCP, Florianópolis

Efecto en el Hormigón de las macro fibras sintéticas



Roesler, J. (2009) Advanced *Course on Concrete Pavement*. University of São Paulo,São Paulo

¿Qué no hacen las fibras?

Las fibras no causan incremento en la capacidad en tracción o en compresión del hormigón

Las fibras no causan mejorías en la resistencia a la flexión o en tracción indirecta en vigas de hormigón

¿Cuáles son las posibles dimensiones de las losas de concreto con el uso de las fibras, en combinación con el empleo de cemento expansivo?

La literatura extranjera, en especial la Británica, nos dice de losas de 20 x 20 m o mismo 30 x 30 m sin agrietamiento de retracción.

Ensayos de Control

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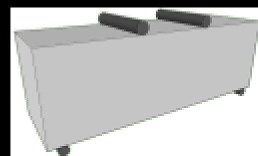
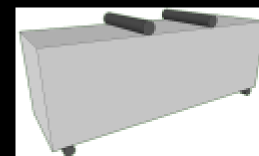
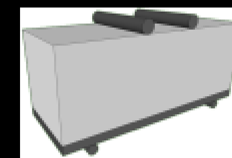
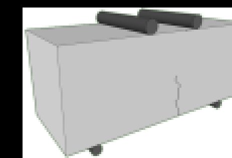
Métodos de ensayo para Hormigón con Fibras

Ítem	ASTM C1609	JSCE-SF4	ASTM C1399
Representación esquemática			 
Tipo de ensayo	closed-loop	open-loop	open-loop
Variable controlada	deflexión de la muestra	deformación vertical de el pistón	deformación vertical de el pistón
Geometría e dimensiones de la muestra	prismático, 150 x 150 x 500	prismático, 150 x 150 x 500	prismático, 100 x 100 x 400
Apoyos / mm	450	450	300
Resultados obtenidos	Resistencias residuales ($Re_{0,75}$ e $Re_{3,0}$), Tenacidad ($T_{3,0}$)	Resistencia equivalente ($R_{e,3}$), Tenacidad ($T_{3,0}$), factor de tenacidad à flexión (σ_b)	Resistencia residual media (ARS)

AMERICAN SOCIETY FOR TESTING MATERIALS. ASTM C1609. Standard test method for flexural performance of fiber-reinforced concrete (using beam with third-point loading). Philadelphia, 2006. 8 p.;
THE JAPAN SOCIETY OF CIVIL ENGINEERS. JSCE-SF4. Method of tests for flexural strength and flexural toughness of steel fiber reinforced concrete. Concrete library of JSCE. Part III-2 Method of tests for steel fiber reinforced concrete. n. 3, p. 58-61, 1984;
AMERICAN SOCIETY FOR TESTING MATERIALS. ASTM C1399. Standard test method for obtaining average residual-strength of fiber-reinforced concrete. Philadelphia, 2007. 6 p.;

Gracias CÓRDOBA

¿PREGUNTAS?