PAVIMENTOS DE CONCRETO CONTINUAMENTE ARMADOS (CRCP)

ALTA DURABILIDADE PARA RODOVIAS E CORREDORES URBANOS DE TRANSPORTE COLETIVO

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1. Introdução
2. CRCP – Aspectos Relevantes
3. Pista Experimental com CRCP
4. Desempenho Inicial
5. Considerações Finais
6. Curiosidades sobre a Prática - EUA
7. Próximos Passos em Pesquisas

1. INTRODUCTION

Concrete pavements → the best solution for heavy traffic (ports, airports, industries, roads and BRT busways)

Fonte: 3bpd

Fonte: extraglobo

PCS – Degraus no tempo

- ✓ **Perda de qualidade de rolamento**

PCS – Juntas serradas p/controle de retração

- ✓ **Perda de qualidade estrutural**
- ✓ **Aspecto mais crítico em PCS**

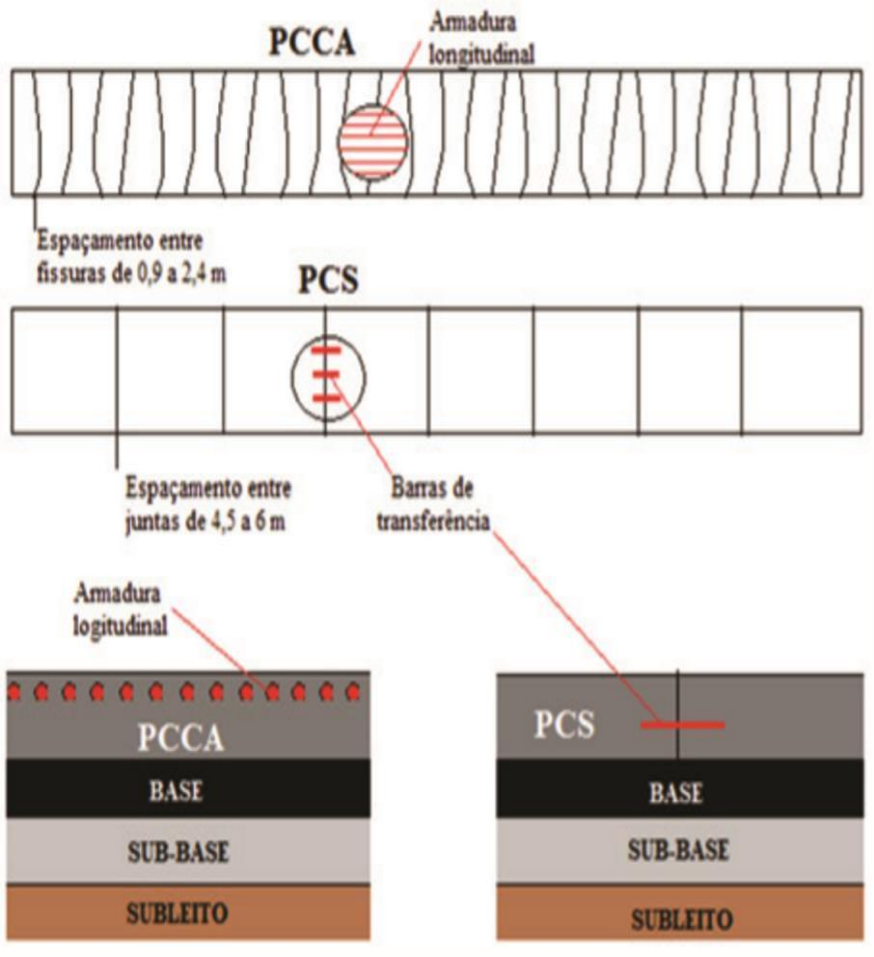
Fonte: Balbo, 2009

1. INTRODUCTION

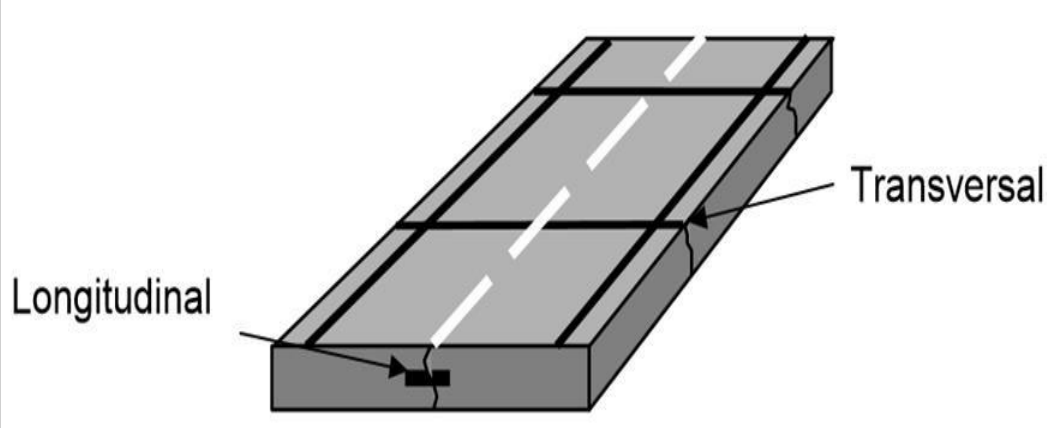
Quais as diferenças?

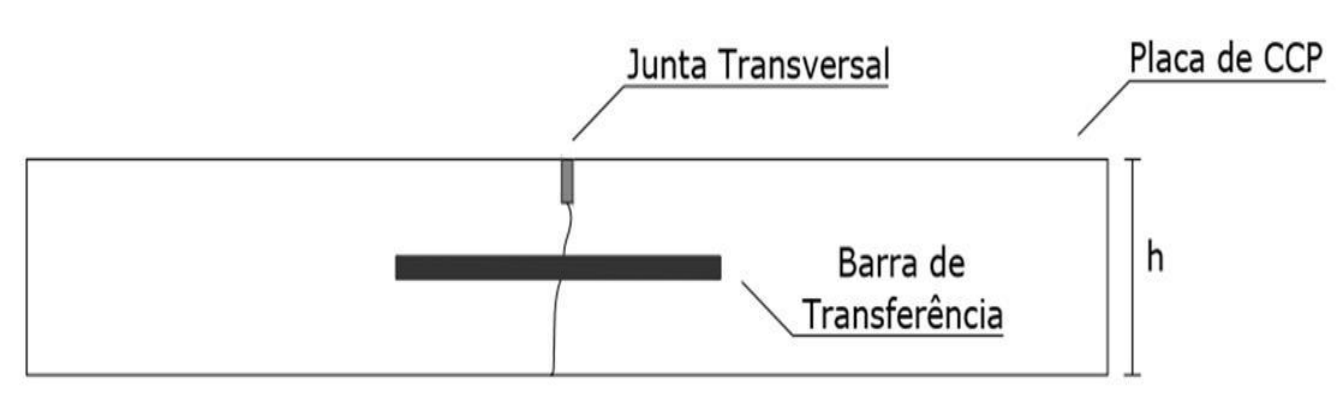
CONTINOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)

JOINT PLAIN CONCRETE PAVEMENTS (JPCP ou PCS)



1. INTRODUCTION





1. INTRODUCTION

CONTINOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)

1. INTRODUCTION

CRCP – Pavimento de concreto sem juntas de contração

First CRCP → USA (1921) – Washington D.C.
First Experimental track – Indiana (1938)

Illinois (1947) and Texas (1958) → great supporters in using this technology

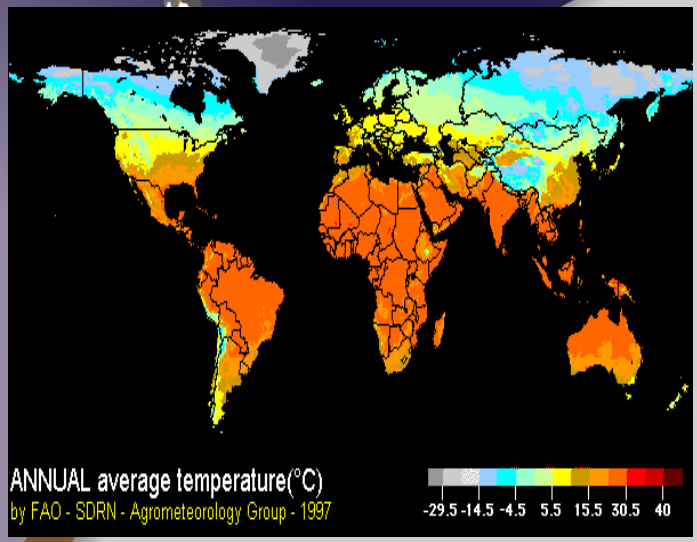
Currently - more than 48,000 km of CRCP highways in the USA
(in Brazil total Federal Road Net is 64.895 km – CNT, 2016)

In the late 1950s → technology migration to Europe → Belgium and Netherlands

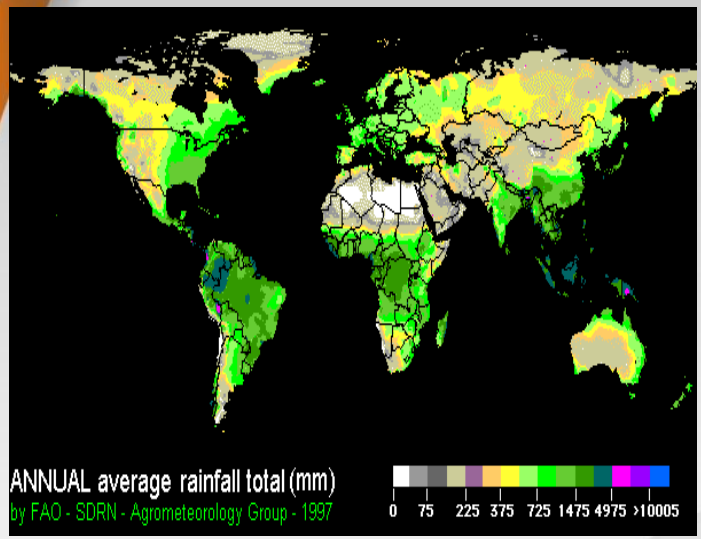
First brazilian experience (2010) → University of São Paulo campus

- **Four sections with 50 m length → considered short → simulation for buses stops**

1. INTRODUCTION



FAO, 2016



FAO, 2016

Summer					
Average Climatological Indexes	Amsterdam (Netherlands)	Brussels (Belgium)	Chicago (Illinois, USA)	Houston (Texas, USA)	São Paulo
Latitude	52°22'N	50°51'N	41°51'N	29°46'N	23°20'S
Min. Temp. (°C)	12,9	12,8	21,4	23,3	19,8
Max. Temp. (°C)	20,5	21,6	24,7	34,4	29,5
Precipitation (mm)	288,6	210	306,1	571,5	800,6
	Winter				
Min. Temp. (°C)	1,4	1,1	-7,7	3,9	13,6
Max. Temp. (°C)	7,4	6,2	0,4	18,3	23,6
Precipitation (mm)	164,1	254	721,4 / 146,6*	215,9	1[illegible]3
Período de chuvas	Summer	Winter	Winter	Summer	Summer

Significant differences between temperate and tropical weather

Influence on CRCP behavior

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2. CRCP - RELEVANT ASPECTS

Fissuras aleatórias → controladas pela taxa de aço na seção

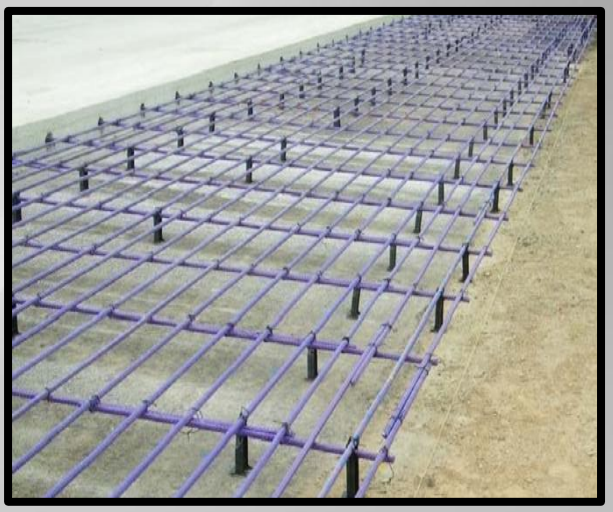
Armaduras sem função estrutural → acima da linha neutra (-)

Função da armadura: Manter fissuras muito apertadas e fechadas → grande eficiência de transferência de cargas nas fissuras (LTE)

Espessura do concreto: similar ao PCS → CRCP custa > 40%

Custos de manutenção→ CRCP é 80% mais econômico que PCS

Houben *et. al.*, 2015



California Department of Transportation, 2015

2. CRCP RELEVANT ASPECTS

Crack width → up to the 1990's crack spacing was the main performance control factor in CRCP

Modifications in projects in Belgium – percentage of stell on cross section

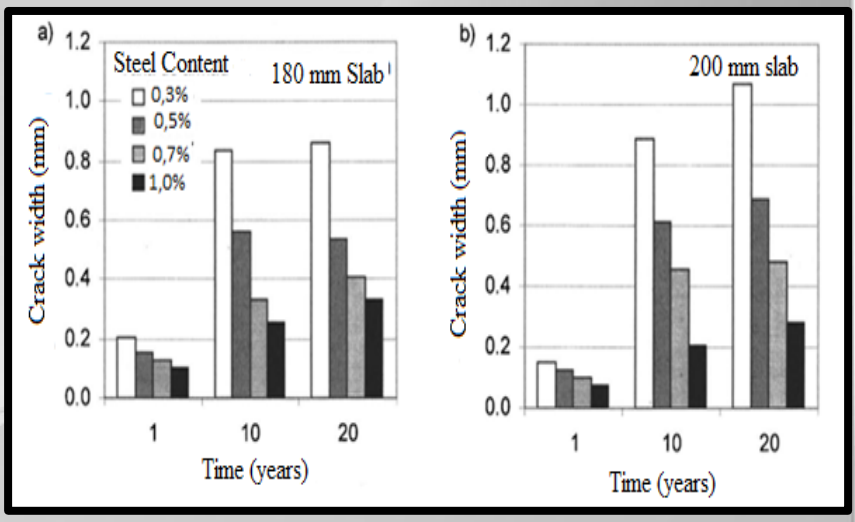
1970 to 1977 → 0.85%
From 1977 to 1990 → 0.67%
From 1990 → 0.75%

Main factor for design and control from the 1990's → change in analisys focus: e → w

Influence in LTE of water and compressible materials infiltration

METAS

w < 1 mm → infiltration
w < 0.63 mm (0°C) → USA
w < 0.5 mm (0°C) → Europe



Kohler and Roesler, 2005

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2. CRCP RELEVANT ASPECTS

2016 → First long extension CRCP in Brazil

GOALS:

Cracking pattern analysis of CRCP with four different concretes

Influence of galvanized steel → crack width and LTE

3. EXPERIMENTAL TRACK TEST WITH CRCP IN BRAZIL

PARTNERS

Votorantim Cimentos

Votorantim Metais

Votorantim Siderurgia

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Votorantim | Cimentos

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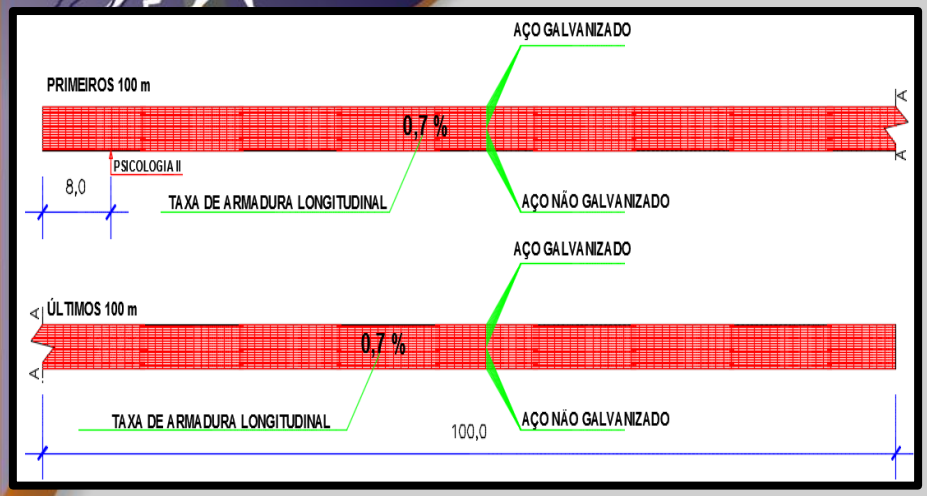
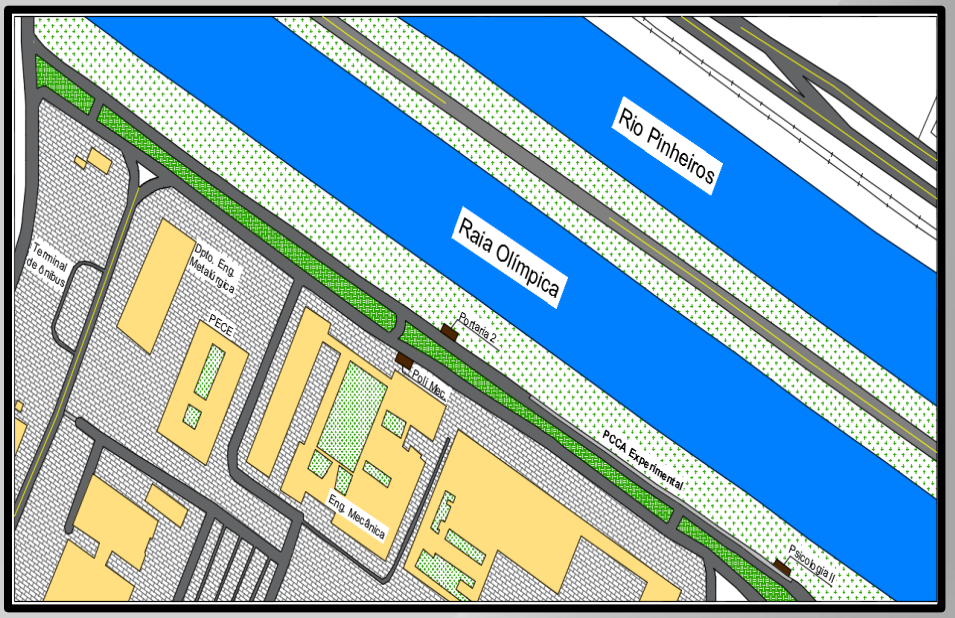
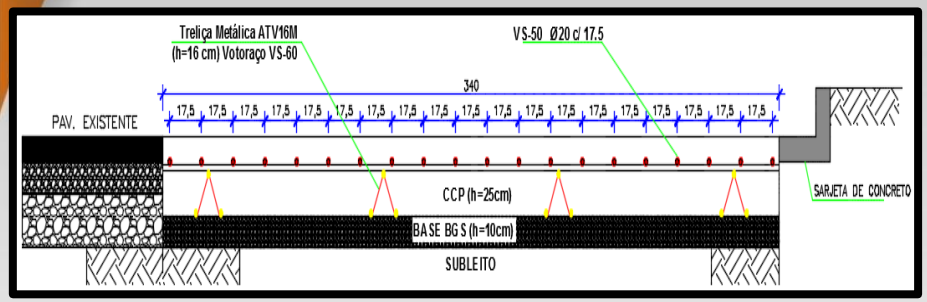
3. EXPERIMENTAL TRACK GEOMETRICAL FEATURES

EXPERIMENTAL CRCP DESIGN







Materiais	Traço 1	Traço 2	Traço 3	Traço 4
Tipo de Cimento	CP IV RS 32	CP II F 40	CP IV RS 32	CP II F 40
Consumo de Cimento (kg/m³)	418	390	402	375
Areia Média (kg/m³)	377	385	478	485
Areia de Brita (kg/m³)	259	265	316	322
Agregado Reciclado (kg/m³)	225	225	-	-
Brita 0 (kg/m³)	225	225	450	450
Brita 1 (kg/m³)	820	820	676	676
Água (kg/m³)	182	182	175	175
Aditivo plastificante (kg/m³)	2,424	2,145	2,723	2,0625
Relação a/c (kg/m³)	0,44	0,47	0,44	0,47

Steel percentage: 0.7%

Concrete Flexural strength: 4.5 MPa @ 28 days

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3. EXPERIMENTAL RESEARCH

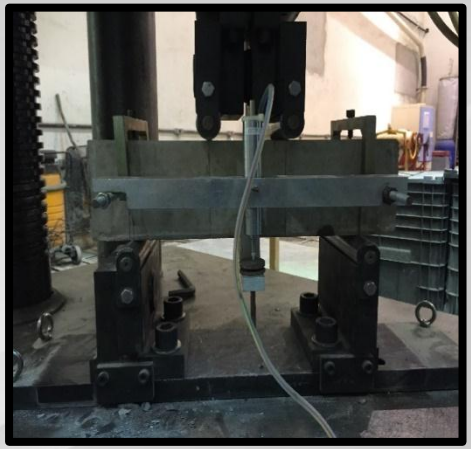
EXPERIMENTAL CRCP CONSTRUCTION (Jan. 18 – Jan. 28, 2016)

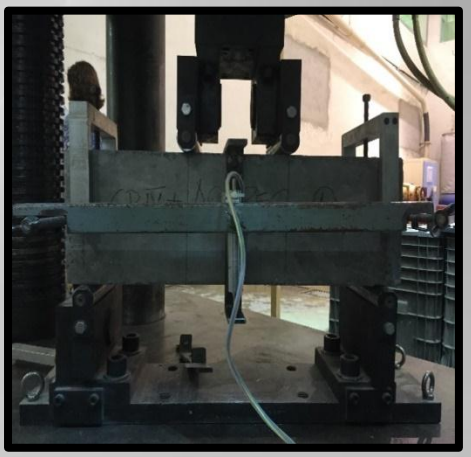
3. EXPERIMENTAL RESEARCH METHOD

TECHNOLOGICAL CONTROL

Concrete	CP IV RS 32 + 50% Rec. Agg.	CP II F 40 + 50% Rec. Agg	CP IV RS 32 + Virgin Agg.	CP II F 40 + Virgin Agg.
Dynamic modulus of elasticity				
$\bar{X}$ (MPa)	45,670	49,069	48,452	52,351
s (MPa)	1,060	845	1,082	1,303
CV (%)	2.32%	1.72%	2.23%	2.49%
Static modulus of elasticity				
$\bar{X}$ (MPa)	34,792	36,214	35,542	39,897
s (MPa)	3,783	3,523	2,401	3,912
CV (%)	10.90%	9.70%	6,80%	9,80%

ID	CP IV RS 32 + 50% Rec. Agg.	CP II F 40 + 50% Rec. Agg	CP IV RS 32 + Virgin Agg.	CP II F 40 + Virgin Agg.
CP 01	6.05	3.99	7.16	5.86
CP 02	5.49	4.31	7.29	6.78
CP 03	5.02	4.65	7.33	6.04
CP 04	4.73	5.30	6.70	6.35
CP 05	4.83	5.02	4.92	5.00
CP 06	5.49	5.39	5.24	5.16
$\bar{X}$ (MPa)	5,27	4.78	6.44	5.87
s (MPa)	0,50	0.56	1.08	0.69
CV (%)	9,5%	11.7%	16.8%	11.7%





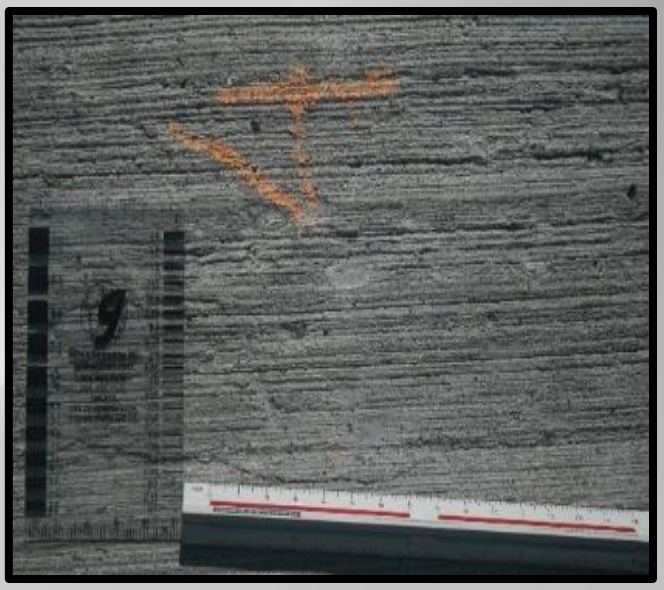
3. EXPERIMENTAL RESEARCH METHOD

CONCRETE CRACKING MONITORING

During the first 60 days after concrete placement, the pavement monitoring to control crack appearance was carried out dayly
April and May → weekly

Two surveys on crack width;

April 4th, 2016 → maximum temperature (31°C)
August 13rd, 2016 → average temperature (13.4°C) – maximum temperature (19.5°C)

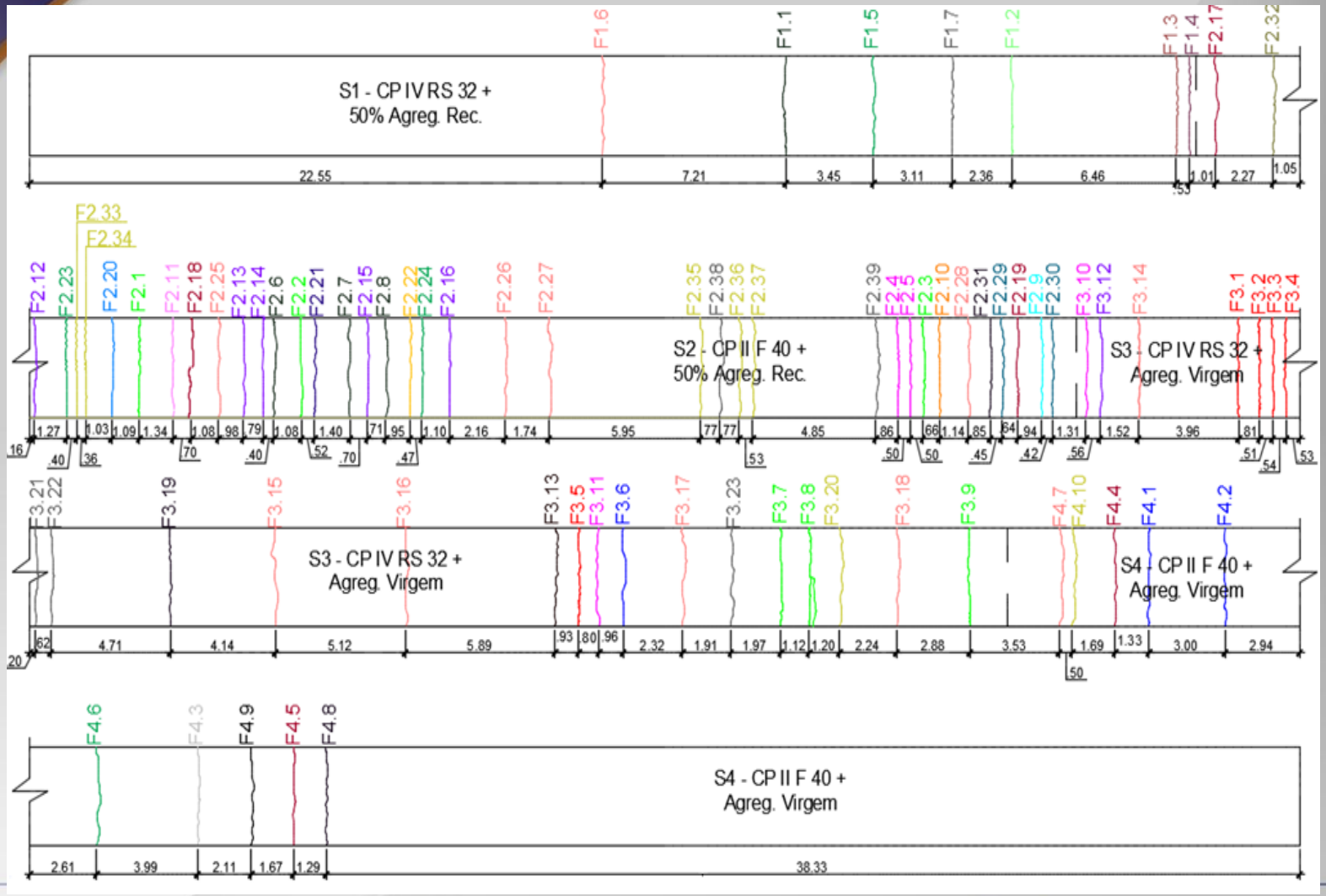


Three positions:

Galvanized steel area
Slab center→ influence of both steels
Ordinary black steel area

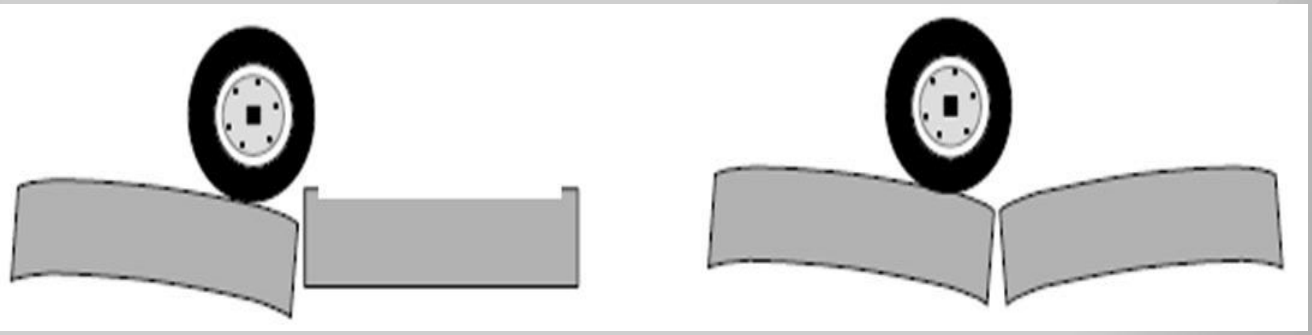
3. EXPERIMENTAL RESEARCH METHOD

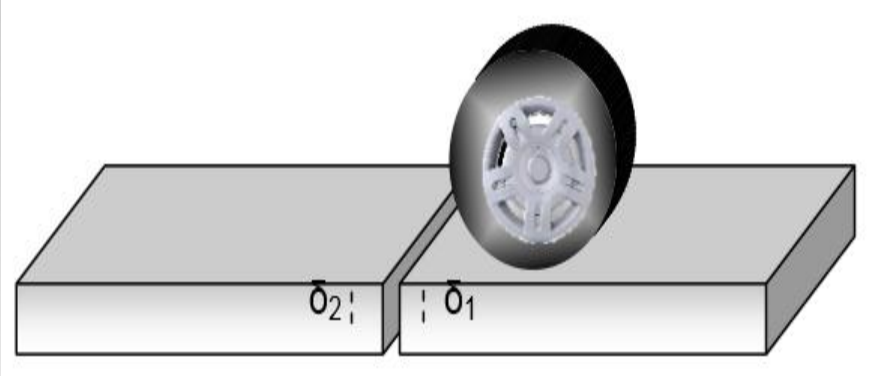
CONCRETE CRACKING MONITORING



3. EXPERIMENTAL RESEARCH METHOD

LOAD TRANSFER EFFICIENCY (LTE) CONCEPT





$$LTE = \frac{\delta_2}{\delta_1} \cdot 100(\%)$$

δ_2 - deflexão na placa carregada

δ_1 deflexão na placa descarregada

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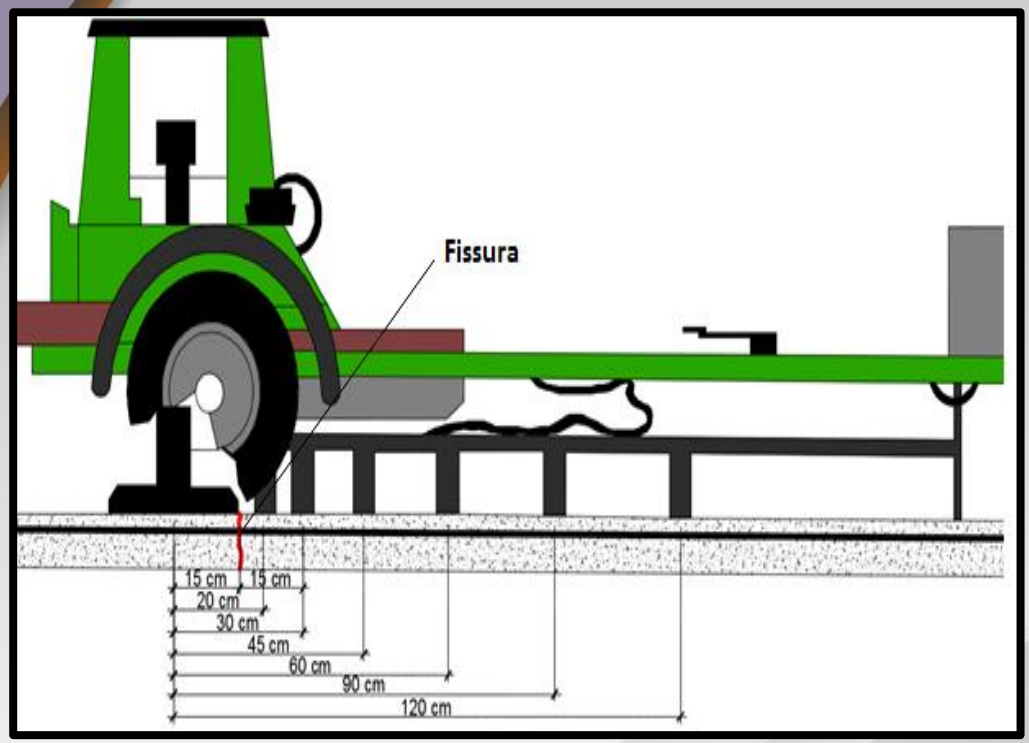
3. EXPERIMENTAL RESEARCH METHOD

FALLING WEIGHT DEFLECTOMETER (FWD) TEST

Cargas aplicadas em duas posições em transversal

Lado com aço galvanizado
Lado com aço comum



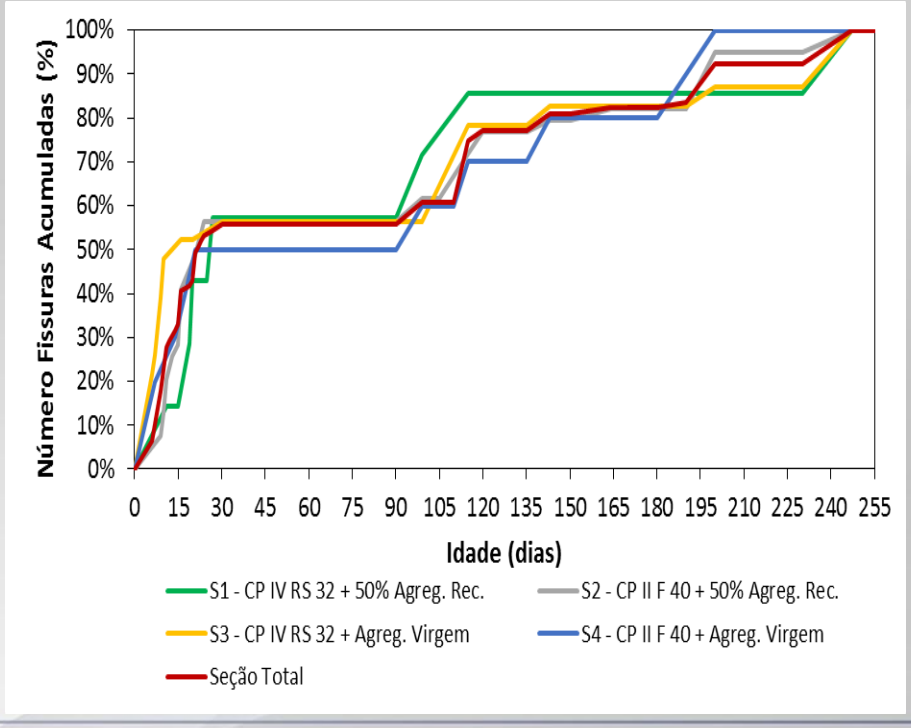
4. INITIAL PERFORMANCE

OBSERVED CRACKING PATTERN

First cracks → during the first week after concrete placement

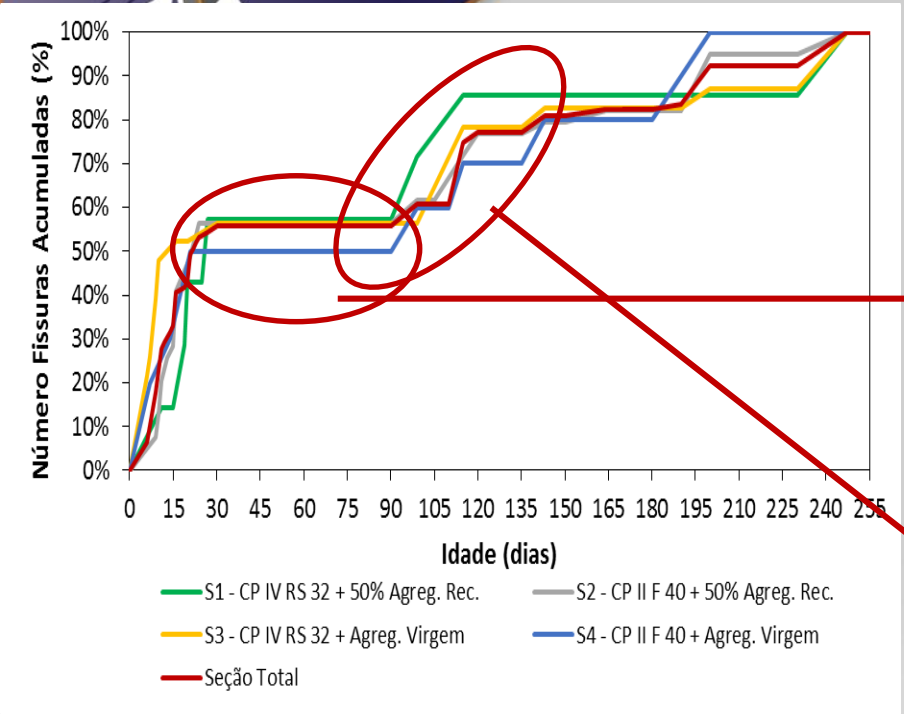
Central area

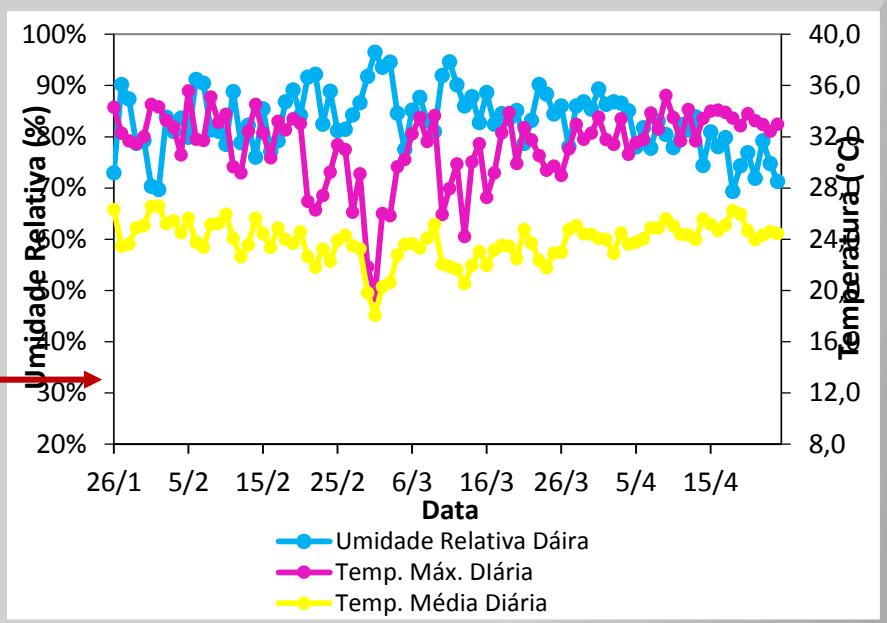
Before the first month, about 60% of the total cracks number had developed → granular base effect

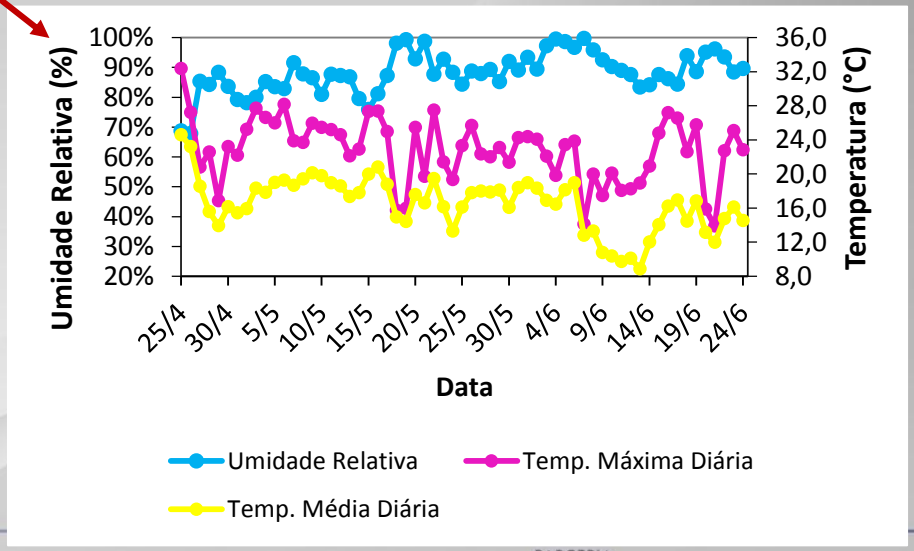


4. INITIAL PERFORMANCE

OBSERVED CRACKING PATTERN







First 90 days

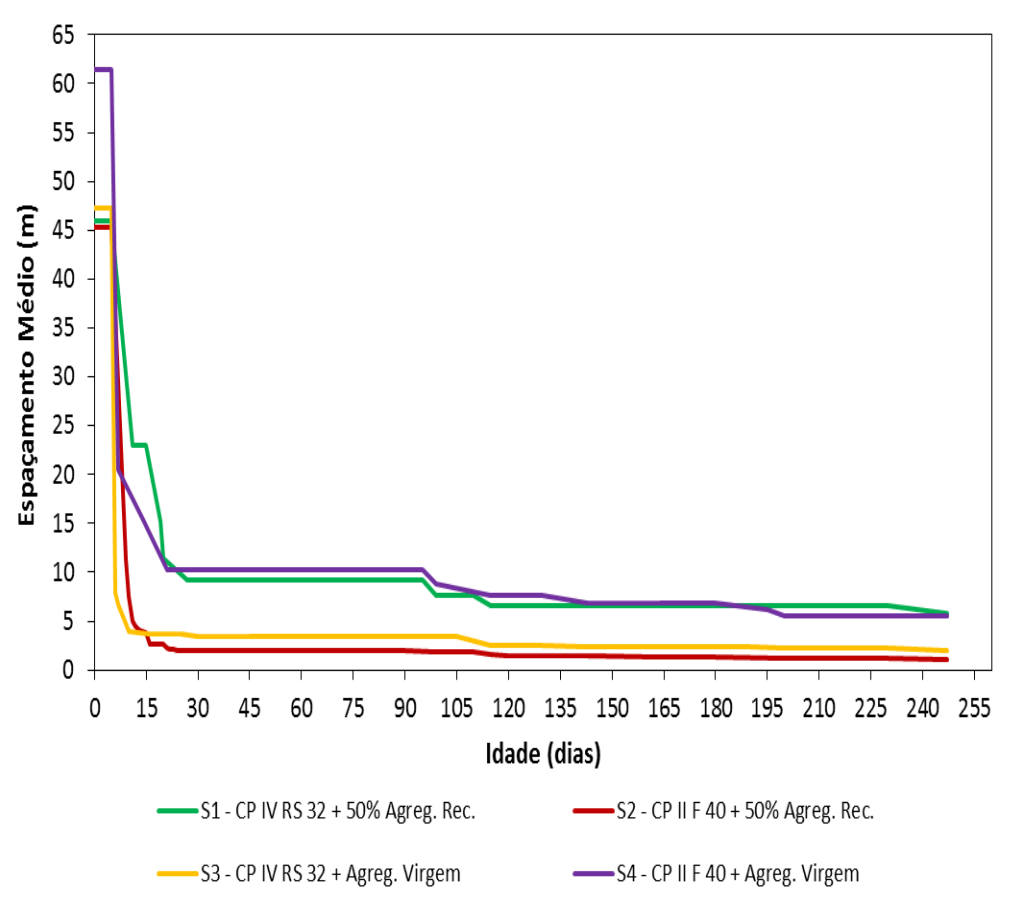
- **Average maximum temperature: 31.3°C**
- **Average daily temperature: 23.8°C**

From 90 to 150 days

- **Average maximum temperature: 22.8°C**
- **Average daily temperature: 16.5°C**

4. INITIAL PERFORMANCE

OBSERVED CRACKING PATTERN



Average crack spacing sections 2 and 3: 1.5 and 2.0 m

More cracks in section 2 → recycled aggregate and cement type effect

Recycle aggregate increases the shrinkage

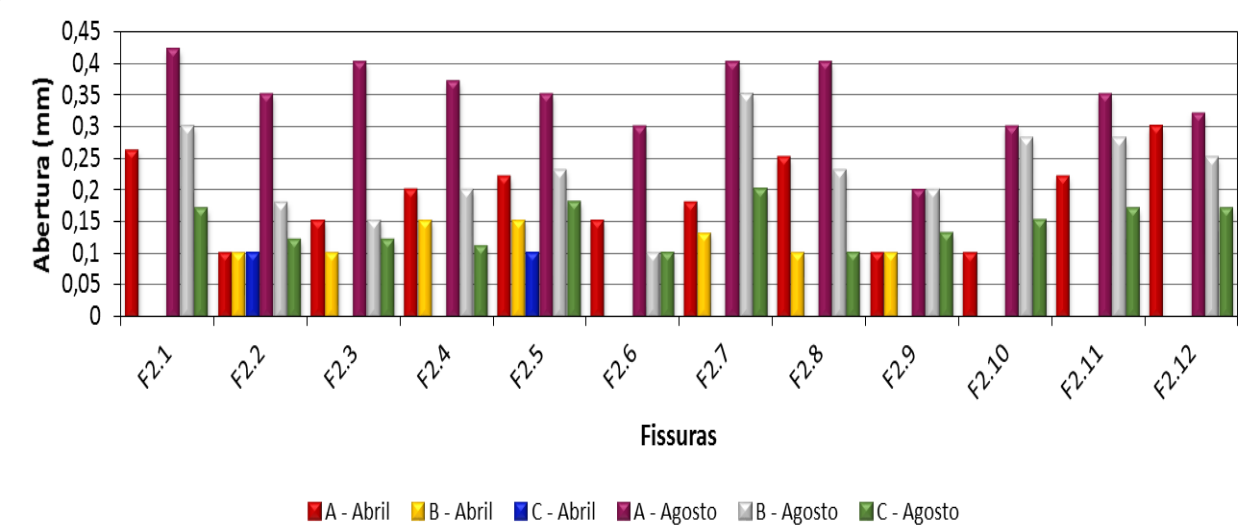
CP II F → 6 to 10% of limestone filler

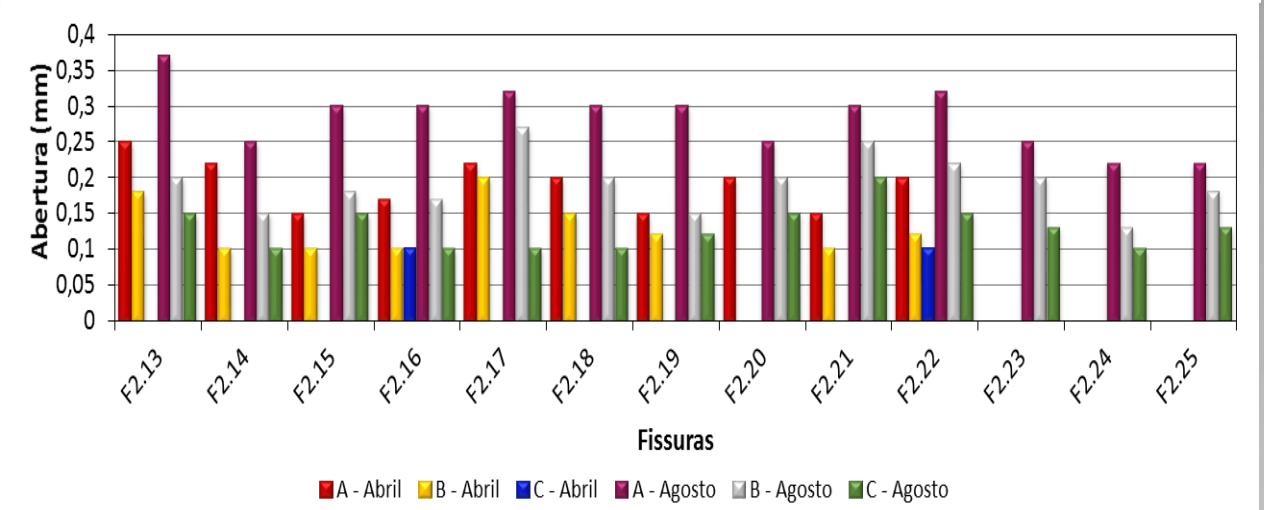
CP IV → 15 to 50% of pozzolanic materials

Crack spacing recorded in section 2 so far is consistent with international literature on CRCP performed with recycled aggregates

4. INITIAL PERFORMANCE

OBSERVED CRACKING PATTERN





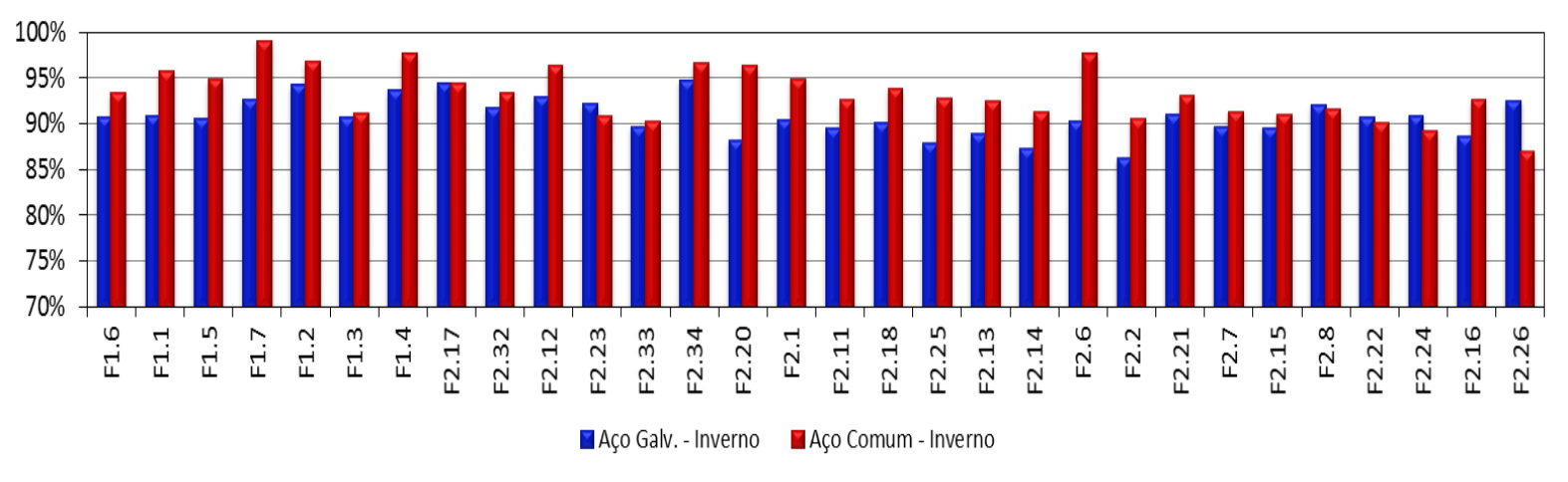
Two surveys on crack width

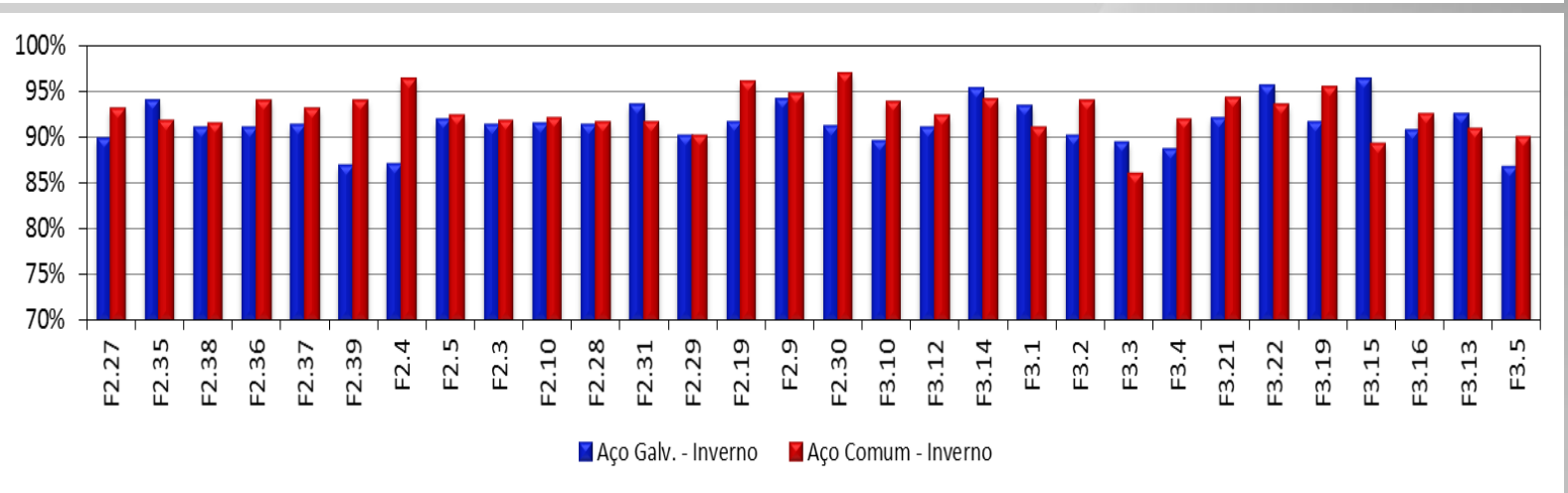
April → crack width range from 0.1 to 0.3 mm

August → crack width range from 0.1 to 0.45 mm

4. INITIAL PERFORMANCE

LOAD TRANSFFER EFFICIENCY





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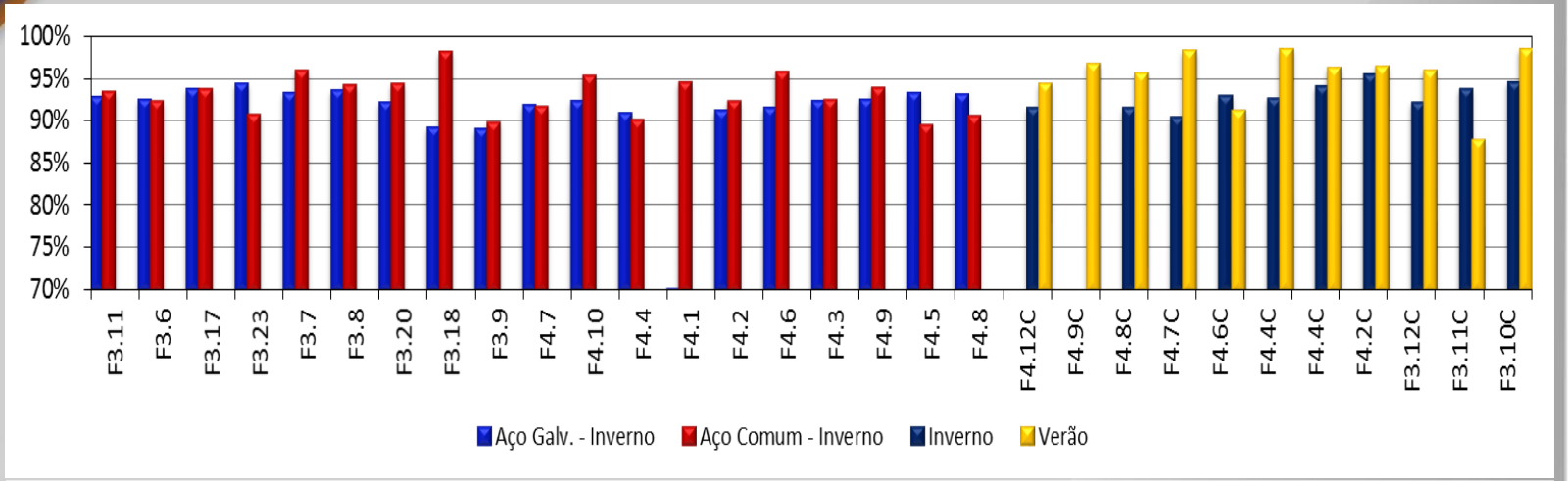
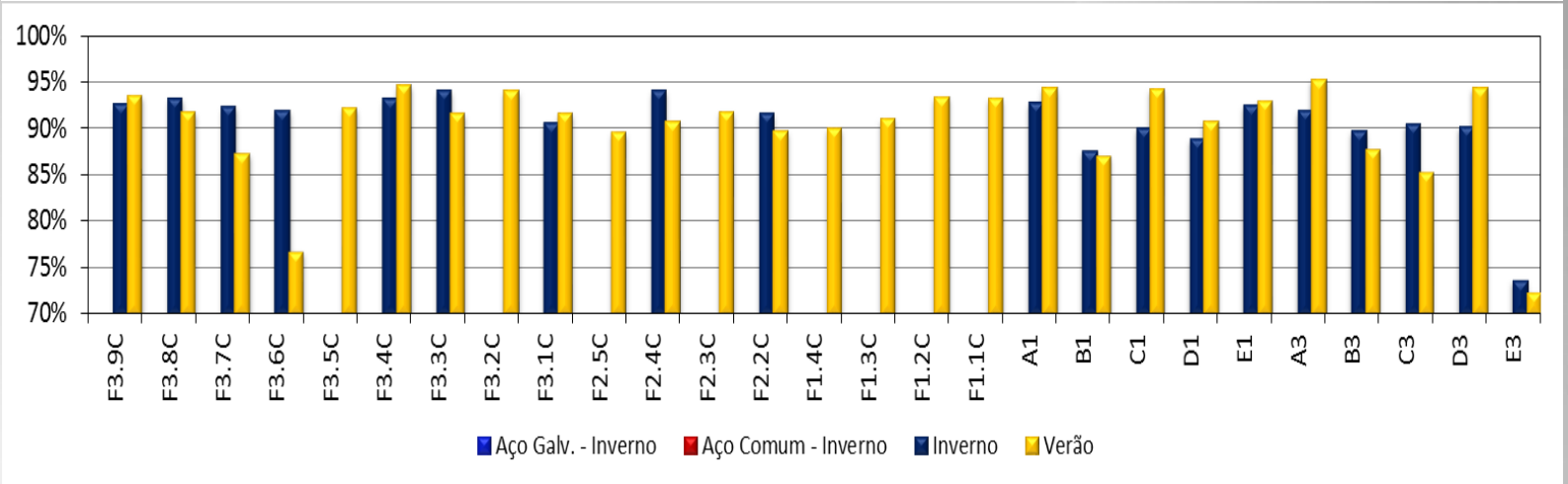
LOAD TRANSFFER EFFICIENCY





SLAB THICKNESSES for highway pavement designs

Federation State	Thickness Ranges (mm)
Illinois	260 (minimum for Interstates)
Oklahoma	230- 310
Oregon	200 - 310
South Dakota	200 - 280
Texas	200 - 380
Virginia	260 - 280

CRSI, 2001)

CONCRETE COMPRESSIVE STRENGTH for highway pavement designs

Federation State	Strength (MPa)
Illinois	25
Oklahoma	21
Oregon	28
South Dakota	28
Texas	25
Virginia	21

CRSI, 2001)

BASE TYPE
for highway pavement designs

Federation State	Thickness (mm) and materials
Illinois	100 of Bituminous Mix
Oklahoma	100 of Bituminous Mix or RCC
Oregon	100 of Bituminous Mix
South Dakota	150 of Granular, Bituminous or RCC
Texas	100 of Bituminous Mix
Virginia	150 to 200 of RCC

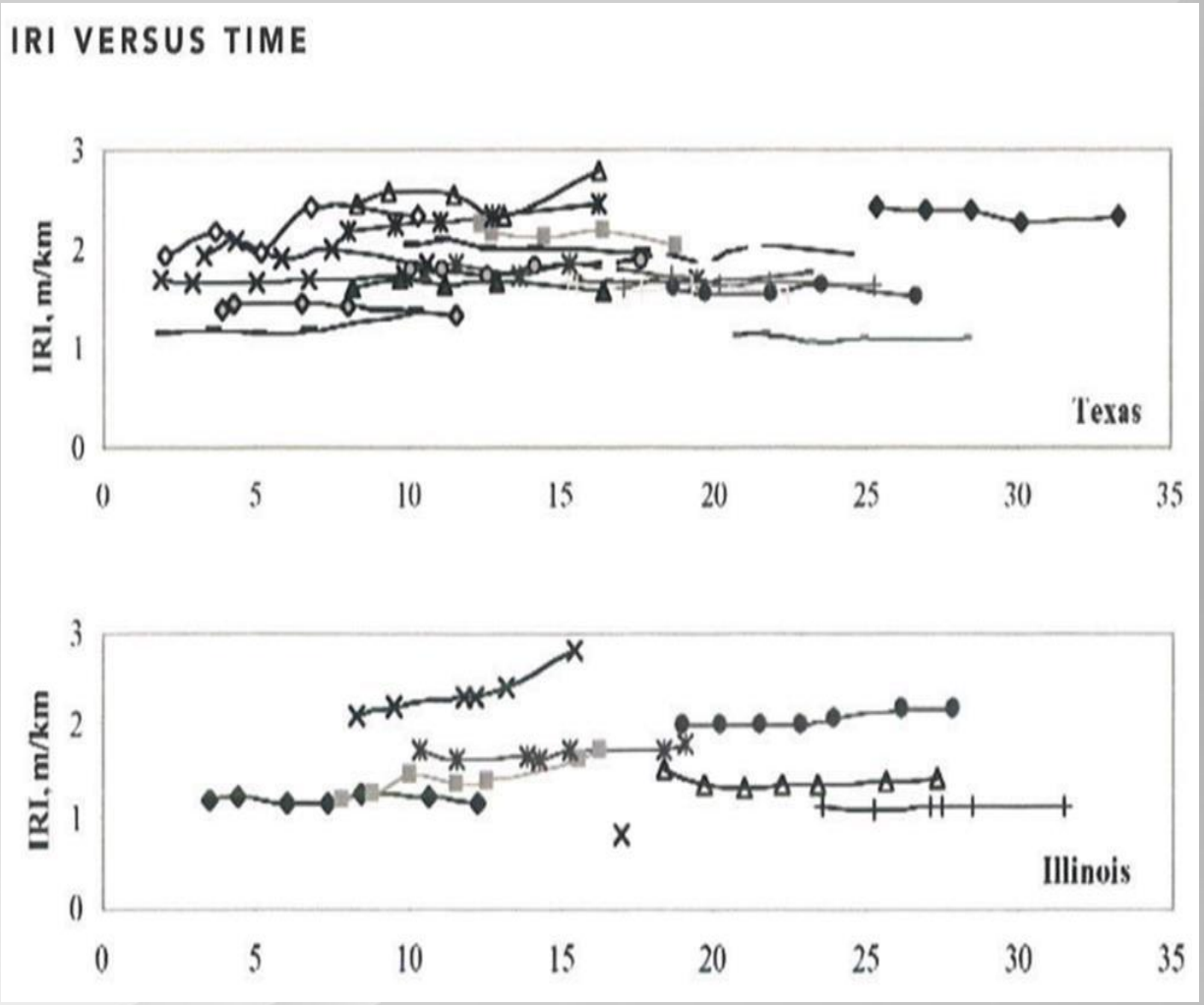
(CRSI, 2001)

STEEL REINFORCEMENT
for highway pavement designs

Federation State	Percent (%) - Depth (mm)
Illinois	0.7 - 90
Oklahoma	0.71 to 0.73 – mid-slab
Oregon	0.6 to 0.7 - 100
South Dakota	0.7 – 75 to 100
Texas	0.5 to 0.7 – mid-slab
Virginia	0,7 – mid-slab

(CRSI, 2001)

6. U.S. PRACTICES CURIOSITIES



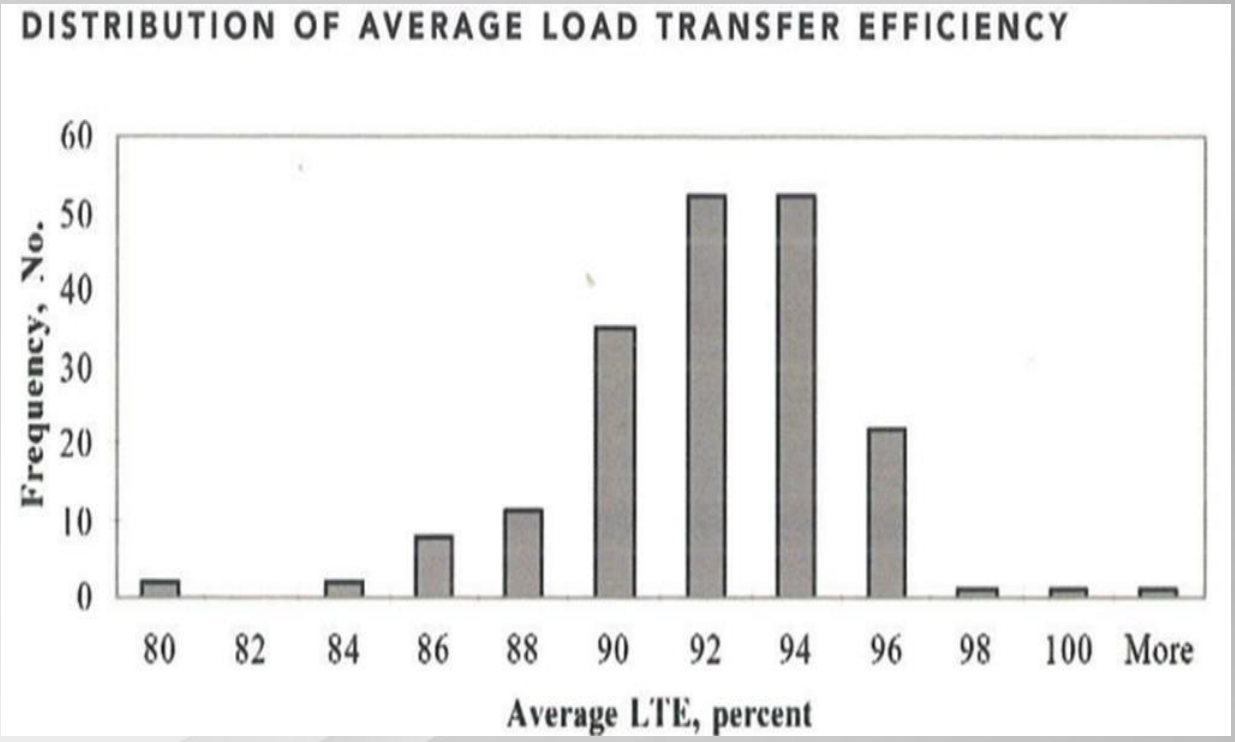
PERFORMANCE ACCORDING TO IRI - highway pavements

(CRSI, 2002)

6. U.S. PRACTICES CURIOSITIES

(CRSI, 2002)

PERFORMANCE ACCORDING TO LTE - highway pavements



7. NEXT STEPS ON CRCP RESEARCH

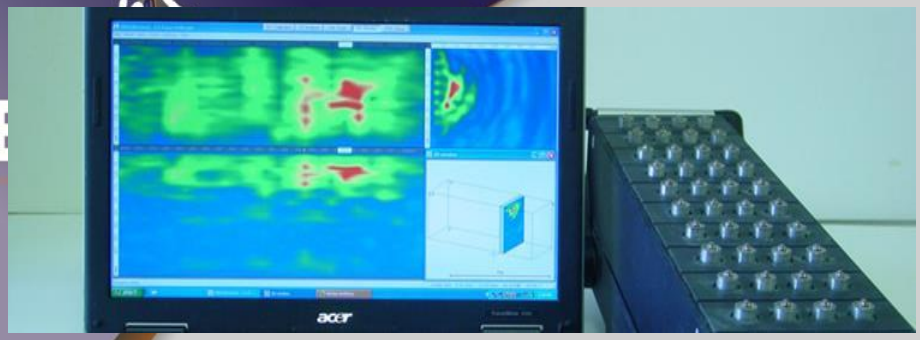
II – São Paulo, 126 (99) **Diário Oficial** Poder Executivo - Seção I quarta-feira, 1º de junho de 2016

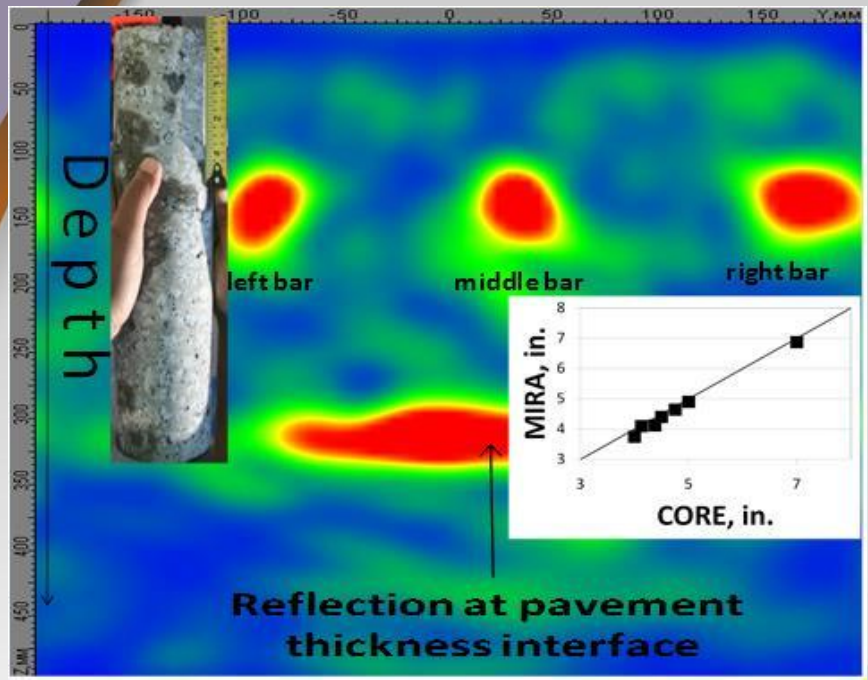
Pavimentado com concreto continuamente armado trecho de pista próximo à Poli serve como campo de provas e recebe intenso fluxo de ônibus

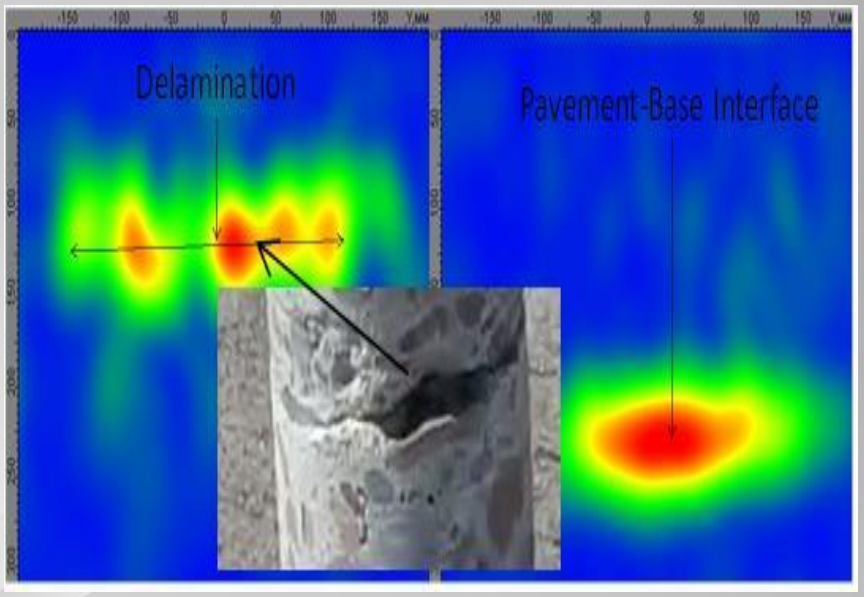
Prof. Balbo – Tomágrafo que avalia pavimentos

Tomógrafo de ondas de baixa frequência

7. NEXT STEPS ON CRCP RESEARCH







OBRIGADO GOIÂNIA!