Durable Continuously Reinforced Concrete Pavements through Active Crack Control

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Road and Railway Engineering

TU Delft

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Crack pattern measurements (spacing, crack width) on 3 motorways:

- **E17 near Ghent (B), no crack control**
- **A50 near Eindhoven (NL), no crack control**
- **E313 near Herentals (B), active crack control**

Concluding remarks

Characteristics CRCP

- Longitudinal reinforcement 0.7%-0.75%
- Reinforcement mid-depth or higher
- Control shrinkage crack pattern (spacing, width)
- Criteria for reinforcement: crack width < 0.4 mm (NL,B)
- No transverse joints
- Increasingly applied in Europe (especially Belgium) and USA on heavily loaded motorways

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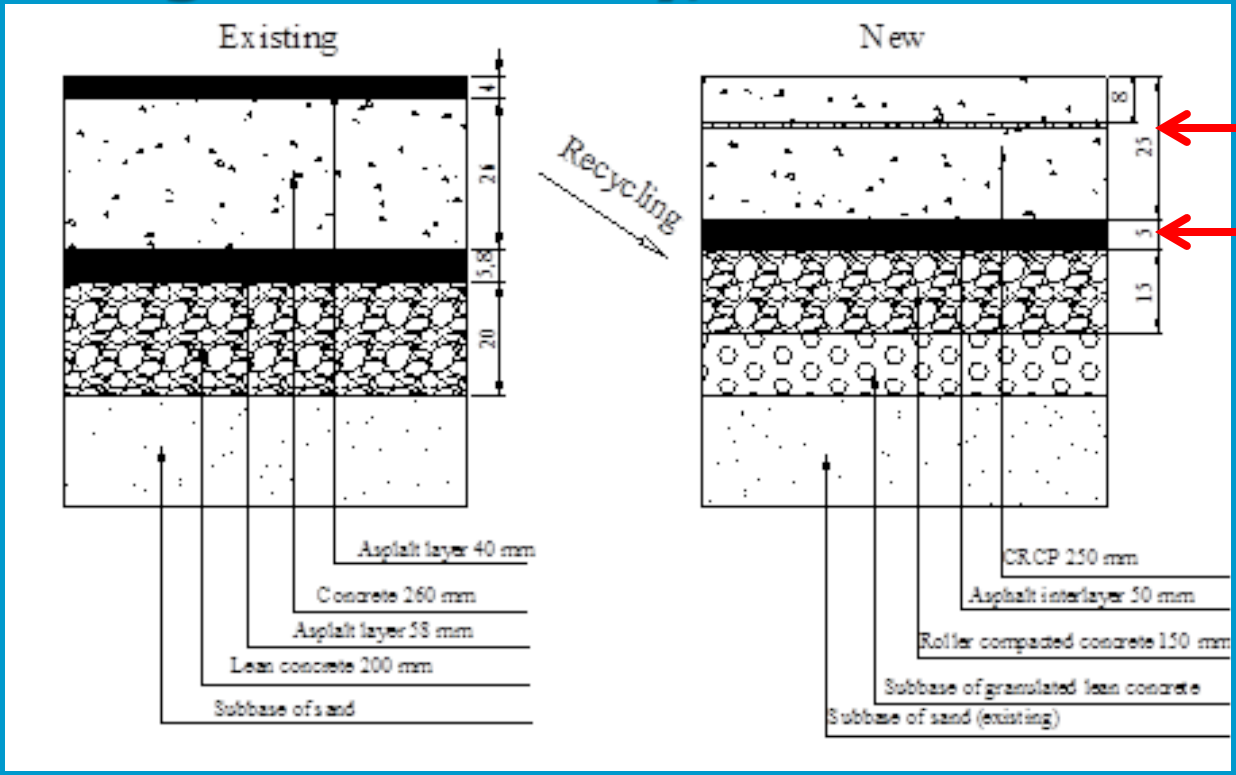
Characteristics CRCP

Pavement structure (reconstruction E17 in Belgium in 2011), dimensions in cm



reinforcement

asphalt interlayer

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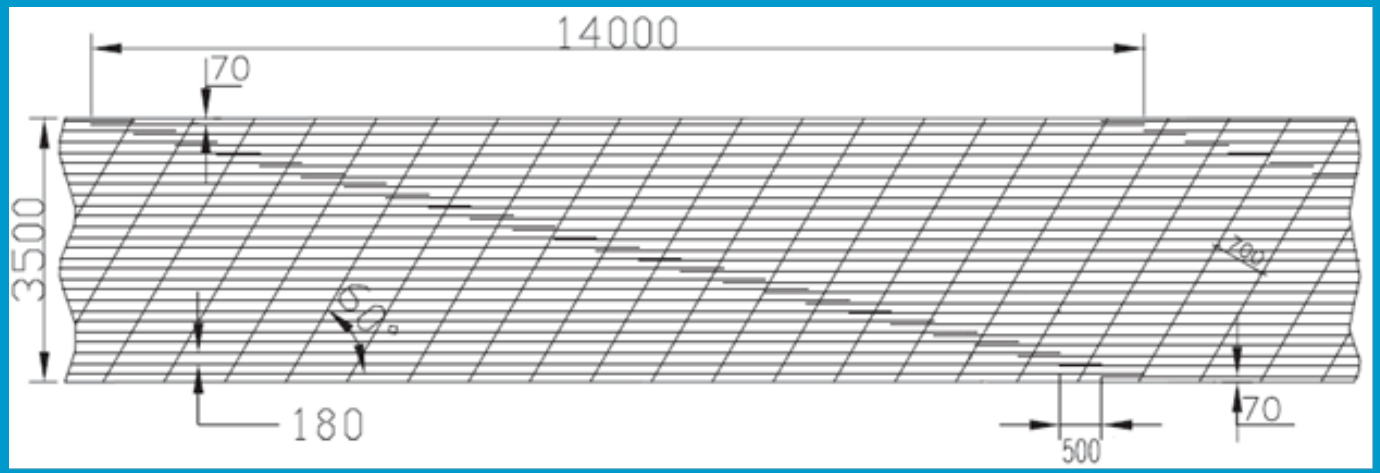
Characteristics CRCP

Longitudinal reinforcement (e.g. ø 20 mm @ 180 mm)



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Characteristics CRCP

Minimum percentage of longitudinal reinforcement to prevent yield of rebars

Concrete grade	C25/30	C30/37	C35/45	C45/55
ω0,min	0.38	0.43	0.47	0.54

Practical percentage of longitudinal reinforcement (in North-west Europe)

Concrete grade	C25/30	C30/37	C35/45	C45/55
ω0	0.7	0.7	0.7	0.75

CRCP investigations

Investigations into crack pattern:

- E17 near Ghent, Belgium:
  . reconstruction in August 2011
  . no active crack control
- E313 near Herentals, Belgium:
  . reconstruction in September 2012
  . active crack control
- A50 near Eindhoven, the Netherlands:
  . 8 years old, 70 mm twinlayer PA wearing course
  . no active crack control
  . reflective cracking in PA wearing course

CRCP on E17 near Ghent (no crack control)

3 test sections

Test section	Chainage (km)	Longitudinal reinforcement
1	44.7 – 45.2	0.75 %
2	45.2 – 46.2	0.70 %
3	46.2 – 46.7	0.65 % + 20 kg/m³ steel fibers

Crack pattern (spacing and width) measurements:

- regularly during 4 days and nights after construction in August 2011
- 5 times in period October 2011 – April 2014

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CRCP on E17 near Ghent (no crack control)

Crack width measurements at pavement surface

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CRCP on E17 near Ghent (no crack control)

Change of crack width measurements ad pavement edge (LVDT measurements on glued studs across crack)

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CRCP on E17 near Ghent (no crack control)

Typical cracks

Y-cracks

Cluster of closely spaced cracks

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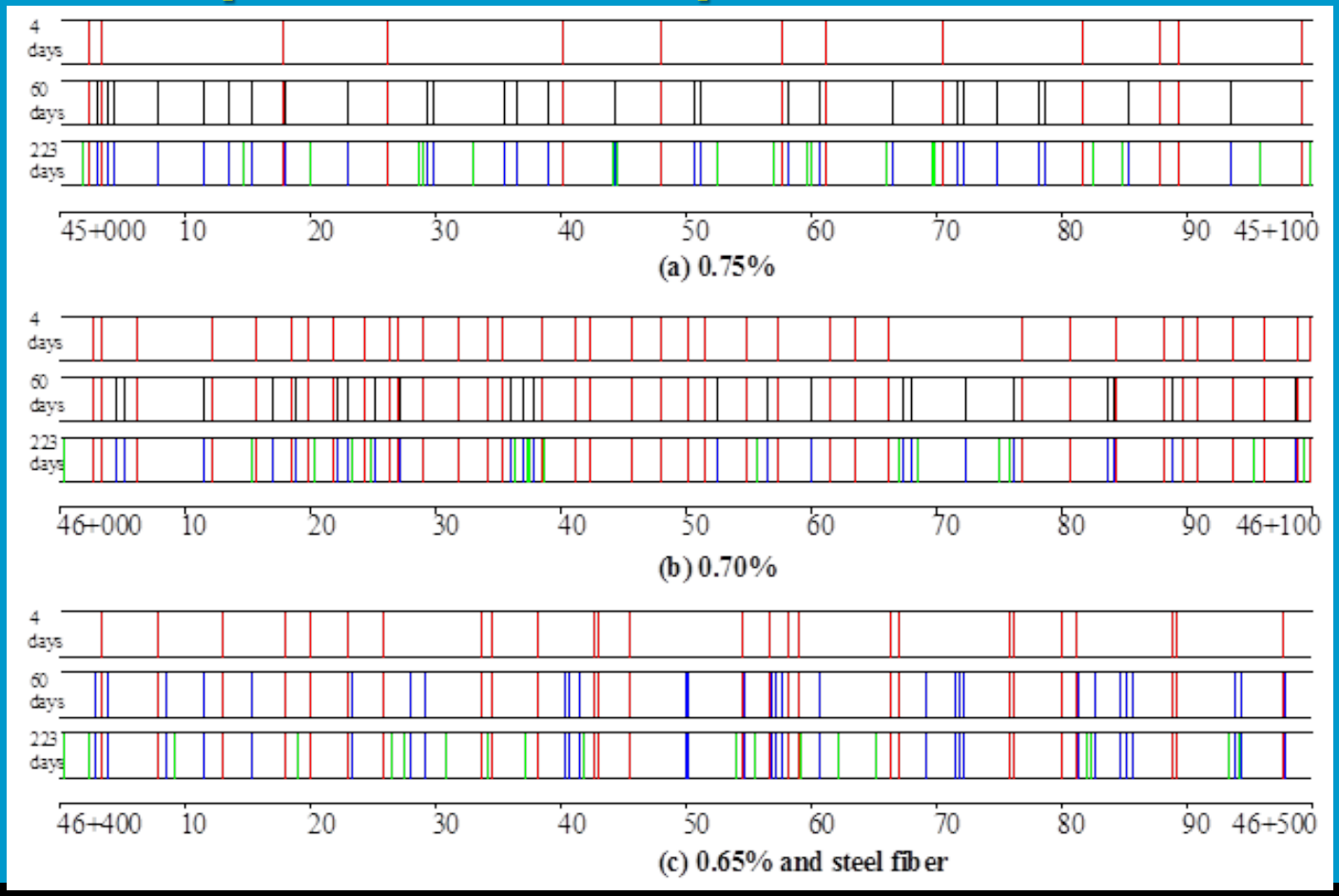
CRCP on E17 near Ghent (no crack control)

Development of crack pattern



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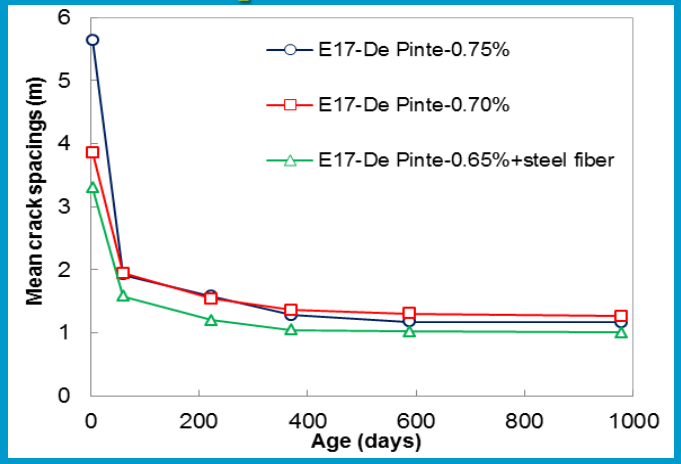
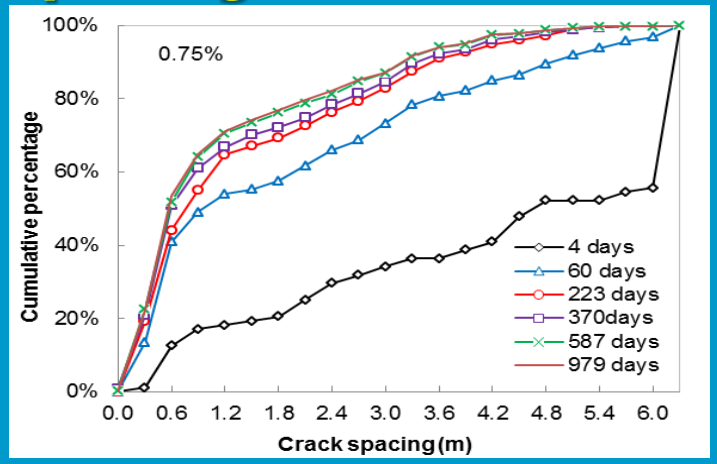
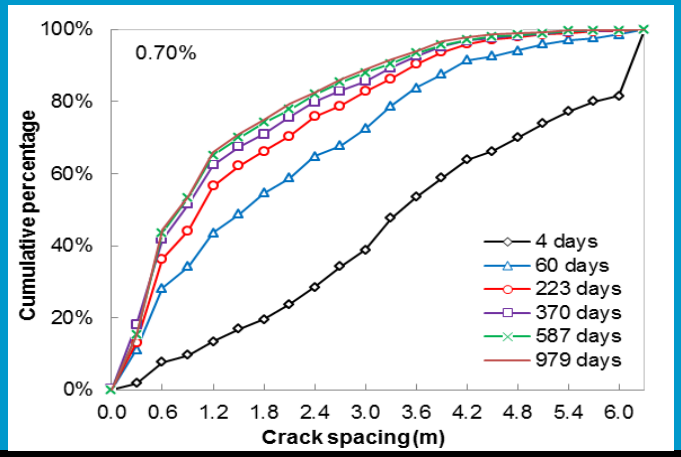
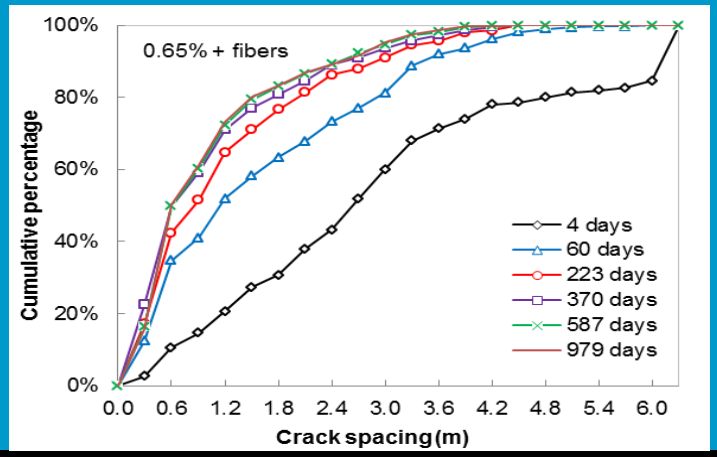
CRCP on E17 near Ghent (no crack control)

Development of crack spacing









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CRCP on E17 near Ghent (no crack control)

Development of crack width at pavement surface in section 1

Age (days)	Temperature at pavement surface (°C)	Number		Crack width (mm)			
		cracks	readings	mean	maximum	minimum	standard deviation
4	30.3	8	40	0.169	0.22	0.10	0.043
223	8.8	14	42	0.117	0.30	0.03	0.076

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CRCP on E17 near Ghent (no crack control)

Crack width changes at pavement edge in test section 1, 3 days after construction

Depth below pavement surface (mm)	Temperature change (°C)	Crack number							mean
		1	2	3	4	5	6	7	
0	22.0-30.2	0.132	0.202	0.328	0.182	0.190	0.170	0.206	0.201
30		0.136	0.212	0.222	0.195	0.154	0.127	0.158	0.172
90*		0.131	0.178	0.192	0.161	0.133	0.084	0.102	0.140

* Centre of longitudinal reinforcement

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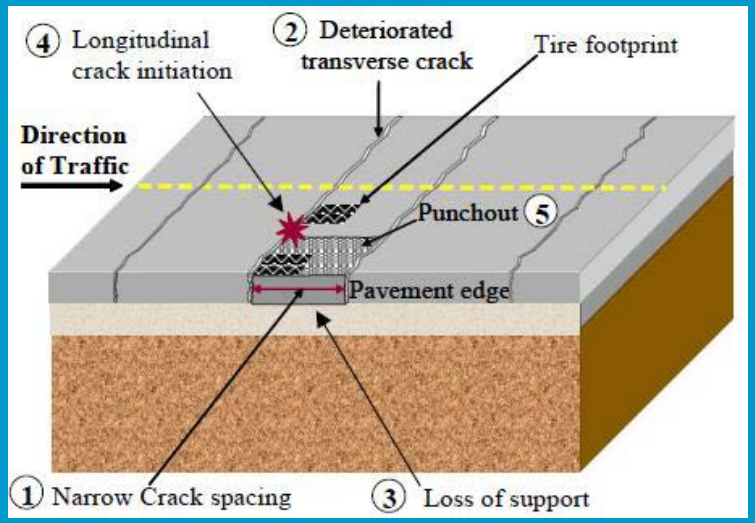
CRCP on E17 near Ghent (no crack control)

Risk of closely spaced cracks: punchouts



Early 2015 1 punchout observed in wheel track of test section 3 (0.65% + 20 kg/m³ steel fibers)

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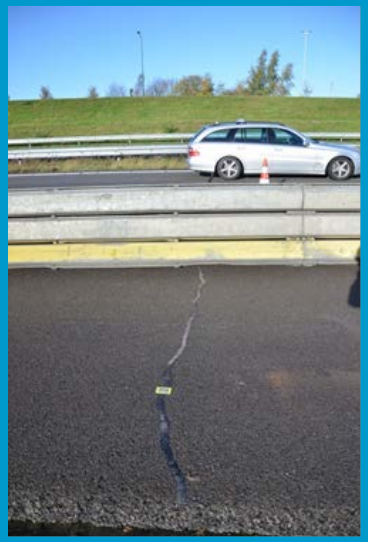
CRCP on A50 near Eindhoven (no crack control)

70 mm twinlayer PA wearing course on CRCP

8 years after construction: reflective cracking



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CRCP on A50 near Eindhoven (no crack control)

100 m section, air temperature 5°C (November 2013), pavement age 8 years, 0.67% longitudinal reinforcement

Crack pattern:

- average crack spacing 1.92 m (large!)
- 27% of crack spacings ≤ 0.6 m (a lot)
- 41% of crack spacings 0.6 – 2.4 m
- 32% of crack spacings ≥ 2.4 m (a lot!)
- 15 out of 52 cracks (30%) reflected through PA

CRCP on A50 near Eindhoven (no crack control)

Cores taken on 9 cracks for crack width measurements

Core number	Crack width (mm)			Sum of crack spacings at both sides of the crack (m)	Reflective crack
	top	middle	bottom		
1	0.35	0.25	0.35	5.90	Yes
2	0.23	0.30	-	4.25	No
3	0.29	0.10	0.25	3.85	Yes
4	0.55	0.30	0.41	4.00	Yes
5	0.35	0.30	0.30	4.00	Yes
6	0.18	0.18	0.20	3.15	No
7	0.20	0.17	0.29	2.45	No
8	-	0.28	0.34	3.25	Yes
9	0.32	0.26	0.33	-	yes
average	0.31	0.24	0.31	-	-

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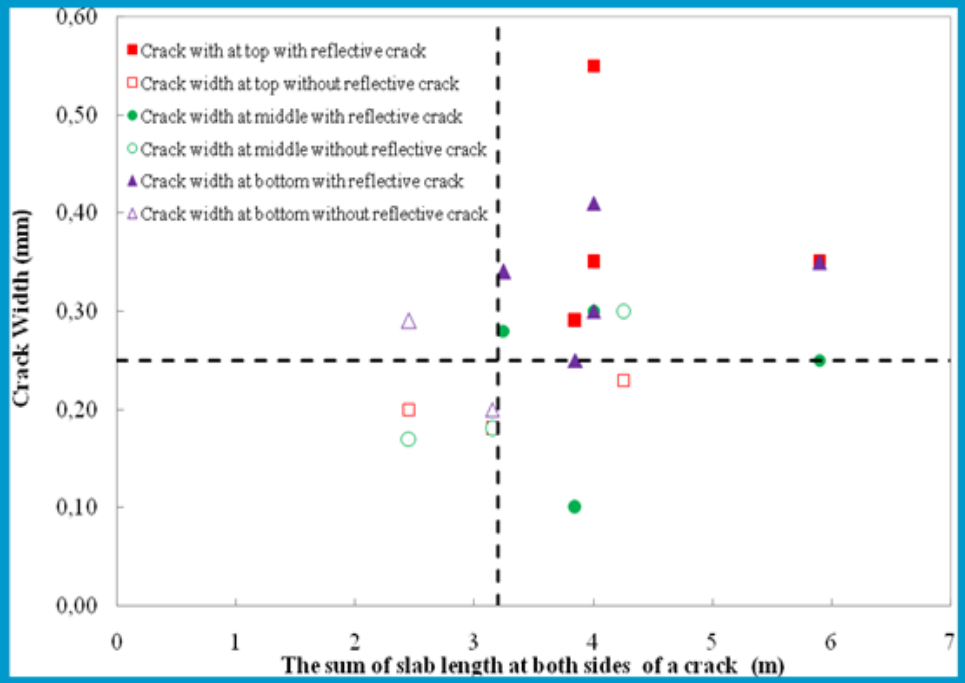
CRCP on A50 near Eindhoven (no crack control)

Cores taken on 9 cracks for crack width measurements



To prevent reflective cracks in this specific case:

- crack width < 0.25 mm
- sum of crack spacings < 3.2 m, i.e. crack spacings < 1.6 m

Mid 2014 (age 9 years) PA milled off and replaced by SAMI plus 70 mm twinlayer PA

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CRCP on E313 near Herentals (crack control)

Reconstruction in 2012

2-lift concrete pavement (50 mm + 200 mm = 250 mm)

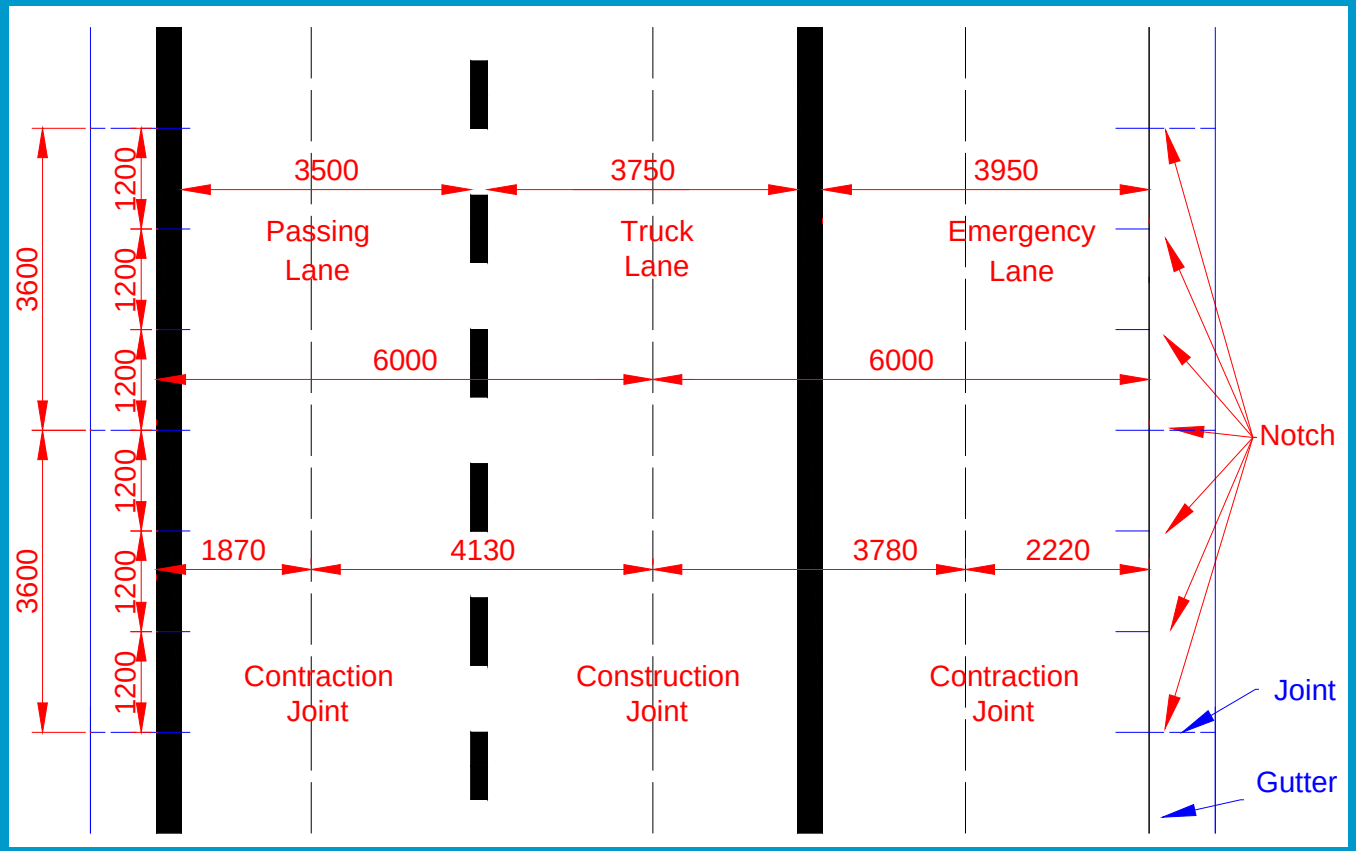
Longitudinal reinforcement 0.75%, 90 mm below pavement surface

50 mm asphalt interlayer

Trial to control crack pattern through surface notches (short transverse saw cuts), applied within 16 hours after construction

CRCP on E313 near Herentals (crack control)

Top view



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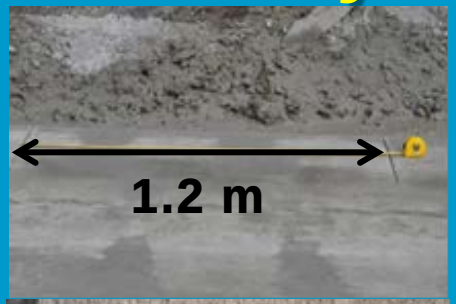
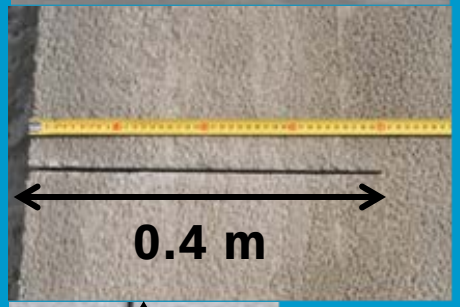
CRCP on E313 near Herentals (crack control)

Geometry of notches



spacing



length

depth

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CRCP on E313 near Herentals (crack control)

Cracks at notches

Depth of saw cut (mm)	Section length (m)	Age (days)	No. of notches (N1)	No. of cracks (N2)	No. of cracks at notches (N3)	Effecti-veness of notches N3/N1 (%)	Percentage of cracks in category (%)			
							Distance to nearest notch (m)			
							0 (N3/N2)	0-0.2	0.2-0.4	0.4-0.6
60	1100	1	897	1	1	0.1	100	0	0	0
		2		73	71	7.9	97.3	0	0	2.7
		3		163	161	17.9	98.8	0	0	1.2
		4		193	191	21.3	99.0	0	0	1.0
		65		664	555	61.9	83.6	2.4	7.7	6.3
		204*		762	597	66.6	78.3	3.8	9.8	8.1
		378		775	606	67.6	78.2	3.8	9.9	8.1
		555**		803	628	70.0	78.2	3.6	10.1	8.1
30	500	123	422	417	245	58.1	58.8	9.4	15.8	16.0
		262*		497	281	66.6	56.5	8.7	17.5	17.3
		613**		505	286	67.8	56.6	8.7	17.2	17.5

* after 1st winter ** after 2nd winter

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CRCP on E313 near Herentals (crack control)

Straight cracks

crack at notch

crack in between 2 notches

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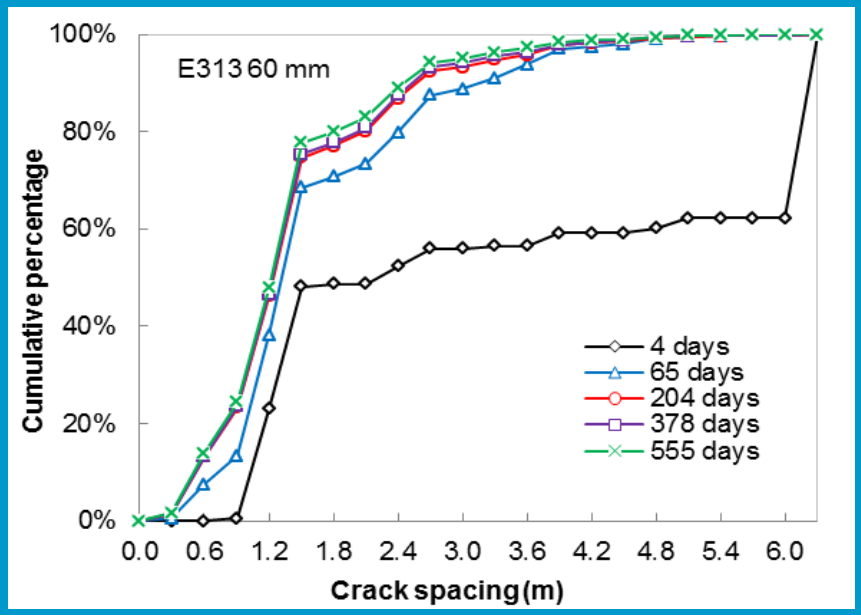
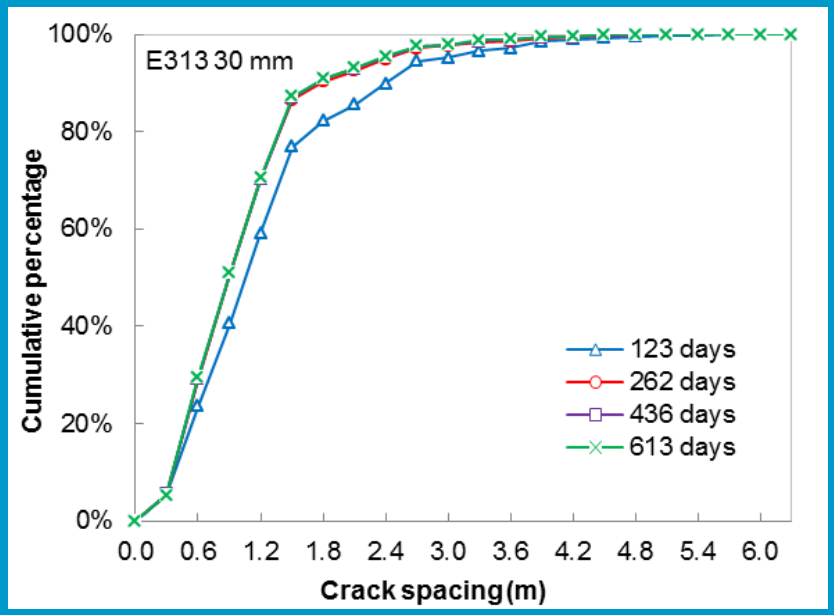
CRCP on E313 near Herentals (crack control)

Crack spacing frequency distributions





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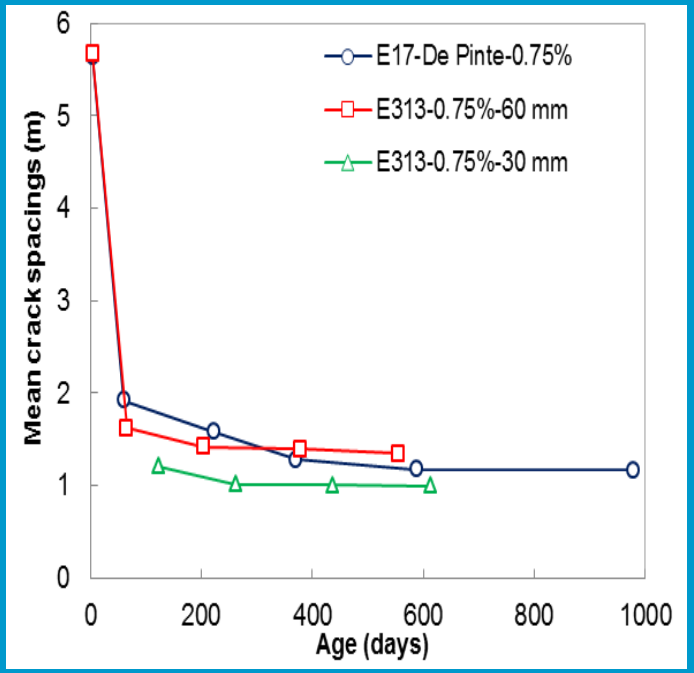
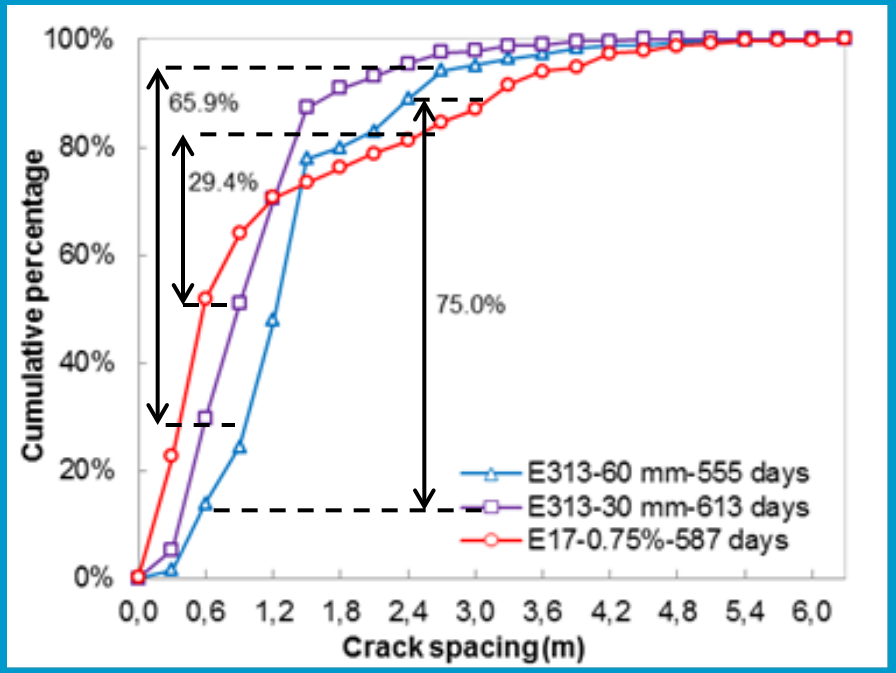
Comparison crack pattern on E17 and E313

Crack spacing after about 20 months (including 2 winters) on E17 and E313, 0.75% reinf.



mean crack spacing



crack spacing frequency distribution

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Comparison crack pattern on E17 and E313

Crack spacing after about 20 months (including 2 winters) on E17 and E313, 0.75% reinforcement

Motorway	Test section	Crack spacing distribution (%)			Average crack spacing (m)
		≤ 0.6 m	0.6 – 2.4 m	≥ 2.4 m	
E17	1	51.8	29.4	19.8	1.18
E313	60 mm notches 30 mm notches	14.0 29.6	75.0 65.9	11.0 4.5	1.35 0.99

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Comparison crack pattern on E17 and E313

Crack width changes due to temperature on E17 and E313, 0.75% reinforcement

Motor-way	Test section	Tempe-rature of pave-ment surface (°C)	Number of cracks	Crack width (mm)			
				mean	maximum	minimum	standard deviation
E17	1	30.3	8	0.169	0.22	0.10	0.036
		2.2	10	0.312	0.35	0.19	0.087
E313	60 mm notches	20.5	17	0.152	0.31	0.10	0.032
		8.0	12	0.201	0.27	0.14	0.034
	30 mm notches	21.0	11	0.198	0.22	0.13	0.035
		4.2	11	0.232	0.32	0.13	0.044

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Concluding remarks

Active crack control through partial surface notches seems quite successful:

- **Less closely spaced cracks and less widely spaced cracks**
- **So more crack spacings in preferred range 0.6 – 2.4 m**
- **Very straight cracks (not interfering)**
- **Cheap measure**

But:

- **Only 3 years of experience**
- **Time of saw cutting partial surface notches very important (current practice: within 16 hours of concrete placement)**

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Muito obrigado

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Types of concrete pavements

1. Jointed plain concrete pavements (JPCP):
- Through joints divided into slabs, 5 * 4 m
- Dowel and tie bars in transverse and longitudinal joints, resp.
- Joints mostly sealed
- No reinforcement at all
- Most widely applied
- Empirical and analytical design methods

Empirical design method: RStO 11 (Ger)

RStO 11 (Germany)

Only JPCP

type of base

traffic loading

(Dickenangaben in cm; —▾— E_{v2}-Mindestwerte in MN/m²)

Zeile	Bauklasse	7	6	5	4	3	2	1
	B	> 32	> 10 - 32	> 3,2 - 10	> 1,8 – 3,2	> 1,0 – 1,8	> 0,3 - 1,0	≤ 0,3
	Dicke des frostsich. Oberbaues[1]	55 65 75 85	55 65 75 85	55 65 75 85	45 55 65 75	45 55 65 75	45 55 65 75	35 45 55 65
	Vliesstoff auf Tragschicht mit hydraulischem Bindemittel auf Frostschutzschicht bzw. Schicht aus frostunempfindlichem Material							
1.1	Betondecke, Vliesstoff[8], Hydraulisch gebundene Tragschicht (HGT), Frostschutzschicht	27 / 15 / Σ 42	26 / 15 / Σ 41	25 / 15 / Σ 40	24 / 15 / Σ 39	23 / 15 / Σ 38		
	Dicke der Frostschutzschicht	- - 33[2] 43	- 24[3] 34 44	- 25[3] 35 45	- - 26[3] 36	- - 27[3] 37		
1.2	Betondecke, Vliesstoff[8], Verfestigung, Schicht aus frostunempfindlichem Material –weit- oder intermittierend gestuft gemäß DIN 18196–	27 / 20 / Σ 47	26 / 15 / Σ 41	25 / 15 / Σ 40	24 / 15 / Σ 39	23 / 15 / Σ 38		
	Dicke der Schicht aus frostunempfindlichem Material	8[4] 18[4] 28 38	14[4] 24 34 44	15[4] 25 35 45	6[4] 16 26 36	- - 27[3] 37		
1.3	Betondecke, Vliesstoff[8], Verfestigung, Schicht aus Frostunempfindlichem Material –enggestuft gemäß DIN 18196–	27 / 25 / Σ 52	26 / 20 / Σ 46	25 / 20 / Σ 45	24 / 20 / Σ 44	23 / 20 / Σ 43	20 / 15 / Σ 35	20 / 15 / Σ 35
	Dicke der Schicht aus frostunempfindlichem Material	3[4] 13[4] 23 33	10[4] 19 29 39	10[4] 20 30 40	1[4] 11[4] 21 31	2[4] 12[4] 22 32	10[4] 20 30 40	- 10[4] 20 30
	Asphalttragschicht auf Frostschutzschicht							
2	Betondecke, Asphalttragschicht, Frostschutzschicht	26 / 10 / Σ 36	25 / 10 / Σ 35	24 / 10 / Σ 34	23 / 10 / Σ 33	22 / 8 / Σ 30		
	Dicke der Frostschutzschicht	- 29[3] 39 49	- 30[2] 40 50	- 31[2] 41 51	- - 32[2] 42	- 25[3] 35 45	- 21[2] 31 41	- 21[2] 31 41
	Schottertragschicht auf Schicht aus frostunempfindlichem Material							
3	Betondecke, Schottertragschicht, Schicht aus frostunempfindlichem Material	29 / 25 / Σ 54	28 / 25 / Σ 53	27 / 25 / Σ 52	26 / 25 / Σ 51	24 / 25 / Σ 49		
	Dicke der Schicht aus frostunempfindlichem Material	Ab 12 cm aus frostunempfindlichem Material, geringere Restdicke ist mit dem darüber liegenden Material auszugleichen						
	Frostschutzschicht							
4	Betondecke, Frostschutzschicht						100 / 21 / Σ 21	100 / 21 / Σ 21
	Dicke der Frostschutzschicht						24[3] 34 44 54	14[3] 24 34 44

1) Bei abweichenden Werten sind die Dicken der Frostschutzschicht bzw. des frostunempfindlichen Materials durch Differenzbildung zu bestimmen, siehe auch Tabelle 8
2) Mit rundkörnigen Gesteinskörnungen nur bei örtlicher Bewährung anwendbar
3) Nur mit gebrochenen Gesteinskörnungen und bei örtlicher Bewährung anwendbar
4) Nur auszuführen, wenn das frostunempfindliche Material und das zu verfestigende Material als eine Schicht eingebaut werden
8) Anstelle des Vliesstoffes kann eine Asphaltzwischenschicht gewählt werden

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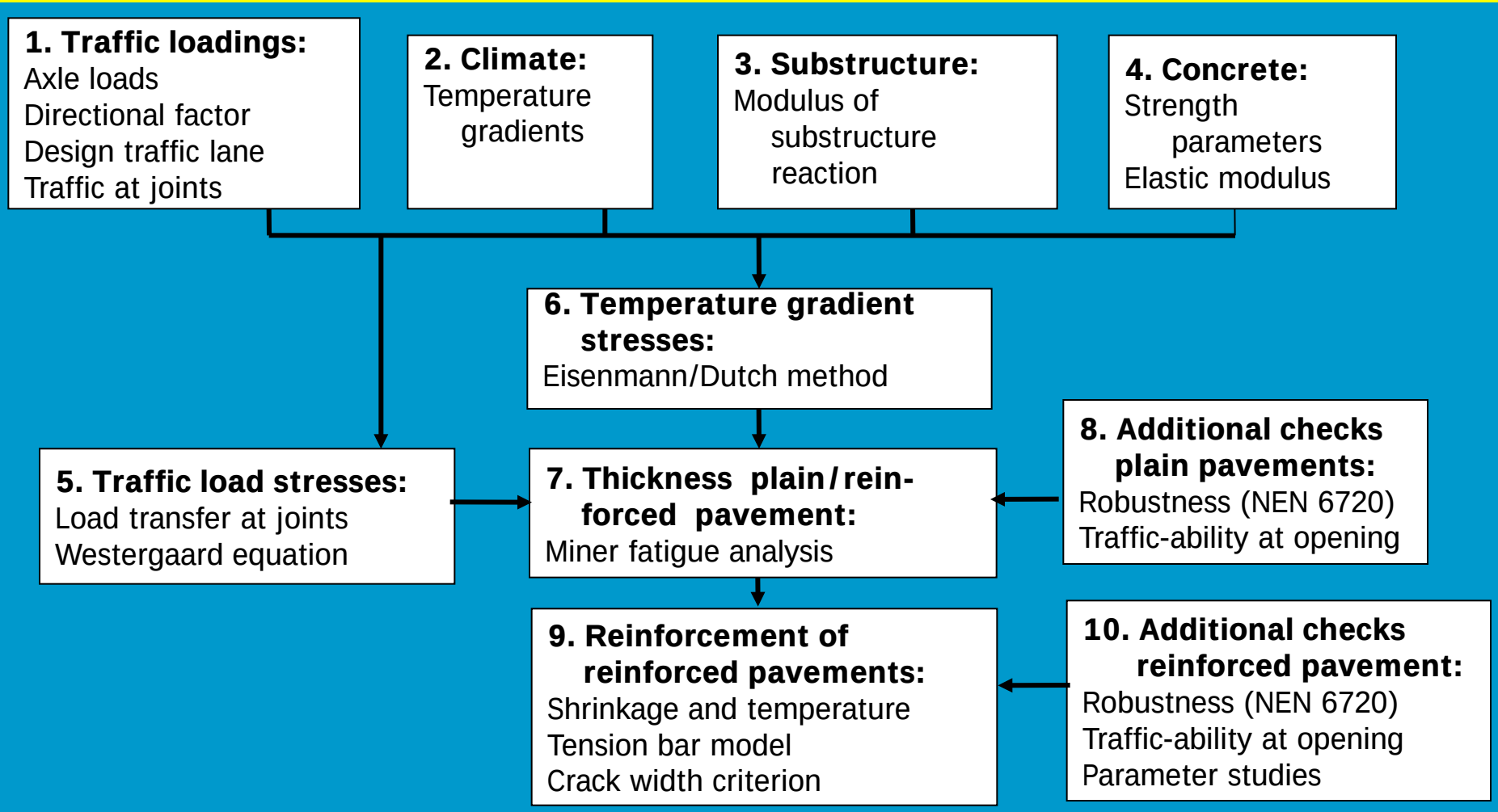
Analytical design method: VENCON2.0 (NL)



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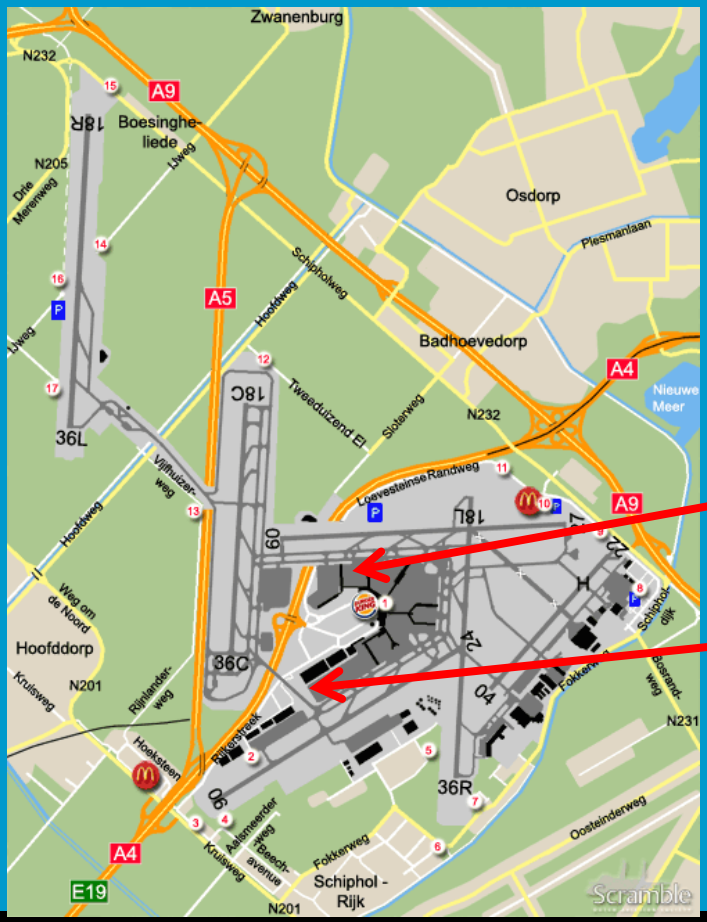
Types of concrete pavements

2. Pre-stressed concrete pavements:

- Large slabs, 130 * 30 m
- Pre-stressed in 2 directions
- Thin pavement (airport: 180 mm)
- Very complex joints
- Most expensive type of pavement
- Few applications (Amsterdam Airport Schiphol)

Types of concrete pavements

Amsterdam Airport Schiphol (55 million passengers/year)



JPCP (new), up to 420 mm thick

Prestressed (old), 180 mm thick

Platforms on airport Rio de Janeiro?

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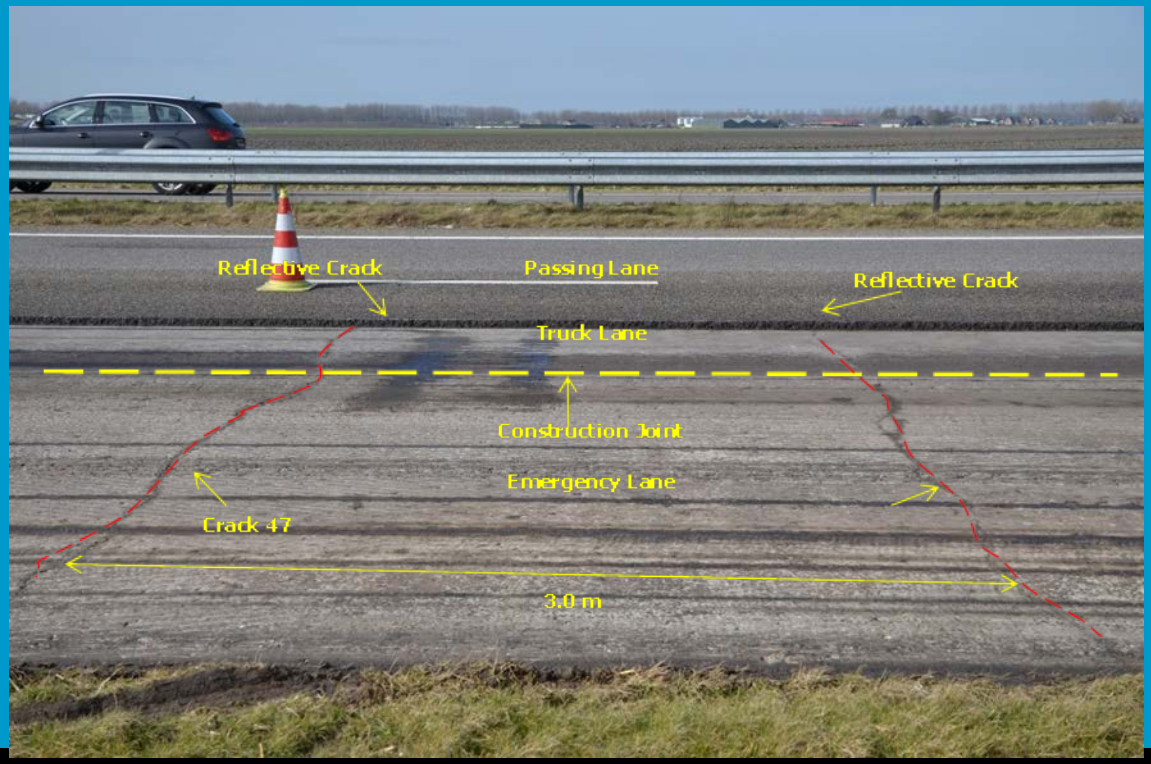
CRCP on A5 near Amsterdam (no crack control)

50 mm single layer PA wearing course on CRCP

13 years after construction: reflective cracking



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CRCP on A5 near Amsterdam (no crack control)

Three 100 m sections, air temperature 2°C-5°C (February 2015), pavement age 13 years, 0.60% longitudinal reinforcement

Crack pattern:

- average crack spacing 4.41 m (very large!!)
- 5% of crack spacings ≤ 0.8 m
- 29% of crack spacings 0.8 – 3.0 m (very few!)
- 66% of crack spacings ≥ 3.0 m (an awful lot!)
- 39 out of 68 cracks (57%!) reflected through PA

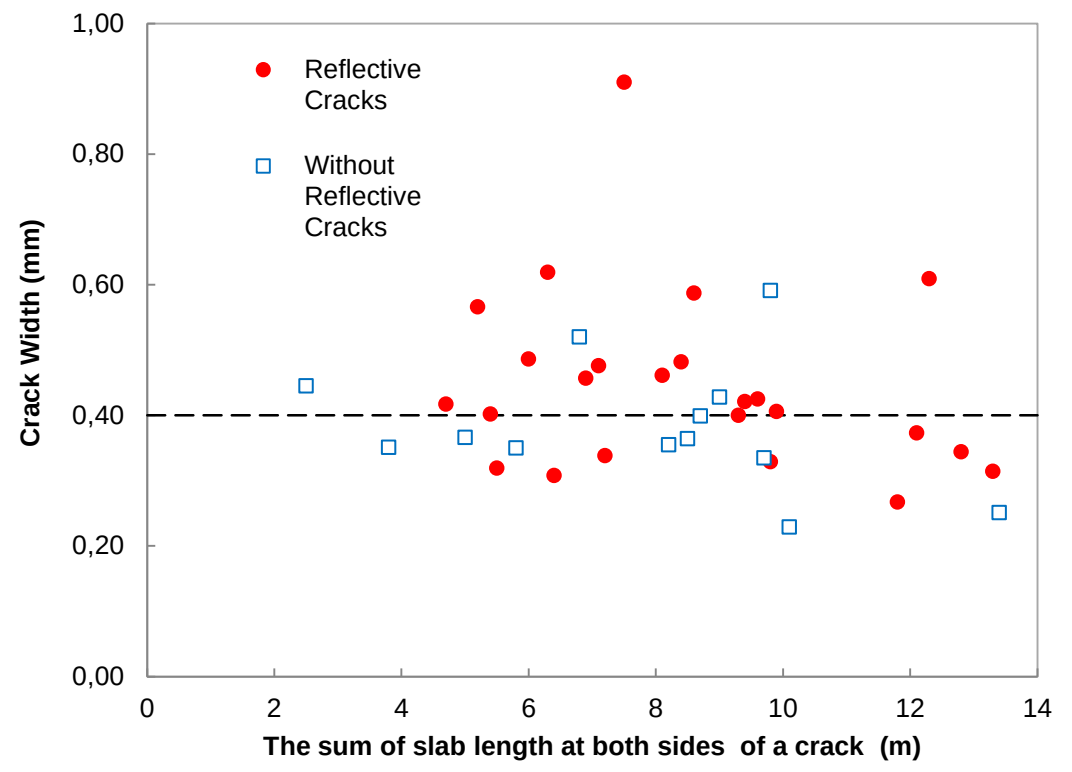
CRCP on A5 near Amsterdam (no crack control)

Crack width characteristics at pavement surface (37 cracks)

Crack width parameter	With reflective cracks	Without reflective cracks
Number of cracks	24	13
Mean crack width (mm)	0.45	0.38
Standard deviation of crack width (mm)	0.14	0.10
Maximum crack width (mm)	0.91	0.59
Minimum crack width (mm)	0.27	0.23

CRCP on A5 near Amsterdam (no crack control)

Crack width characteristics at pavement surface (37 cracks)



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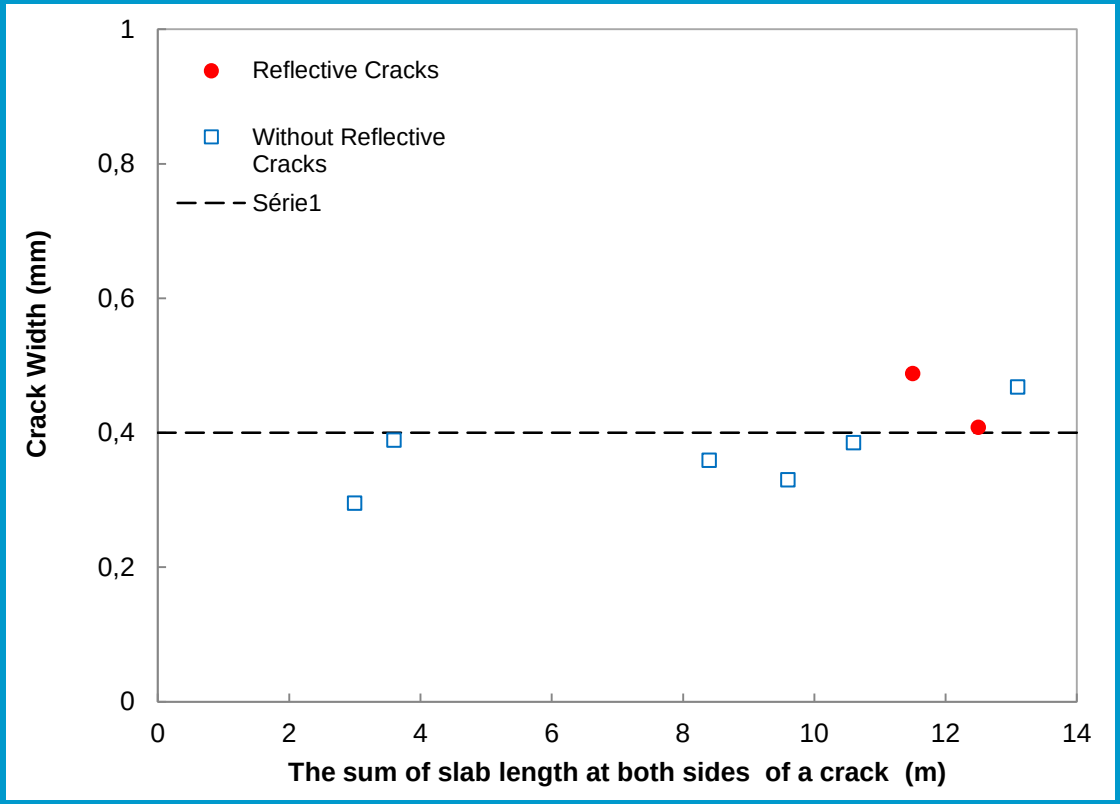
CRCP on A5 near Amsterdam (no crack control)

Cores taken on 12 cracks for crack width measurements

Crack width parameter	With reflective cracks	Without reflective cracks
Number of cracks	2	6
Mean crack width (mm)	0.448	0.371
Standard deviation of crack width (mm)	0.057	0.059
Maximum crack width (mm)	0.488	0.468
Minimum crack width (mm)	0.408	0.295

CRCP on A5 near Amsterdam (no crack control)

Cores taken on 12 cracks for crack width measurements



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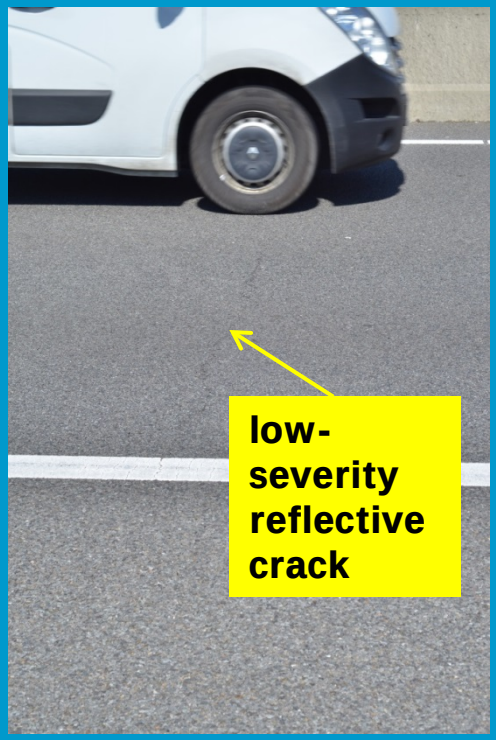
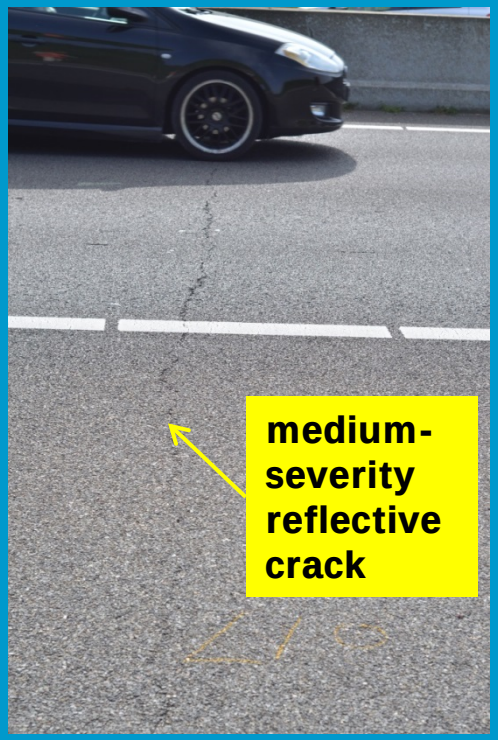
CRCP on A73 near Echt (no crack control)

70 mm twinlayer PA wearing course on CRCP

8 years after construction: few reflective cracks





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CRCP on A73 near Echt (no crack control)

On Eastern carriageway, 5 sections, total 1500 m, air temperature 10°C—›25°C (April 2015), pavement age 8 years, 0.70% longitudinal reinforcement mid-depth

Crack pattern very good:

- average crack spacing 1.88 m
- 18% of crack spacings ≤ 0.8 m
- 67% of crack spacings 0.8 – 3.0 m
- 15% of crack spacings ≥ 3.0 m
- 15 out of 803 cracks (only 2%!) reflected through PA

CRCP on A73 near Echt (no crack control)

On Western carriageway, 6 sections, total 1062 m, air temperature 9°C—›17°C (April 2015), pavement age 8 years, 0.70% longitudinal reinforcement mid-depth

Crack pattern less good:

- average crack spacing 2.63 m (a bit large)
- 11% of crack spacings ≤ 0.8 m
- 57% of crack spacings 0.8 – 3.0 m
- 32% of crack spacings ≥ 3.0 m
- 27 out of 404 cracks (7 2%) reflected through PA

CRCP on A73 near Echt (no crack control)

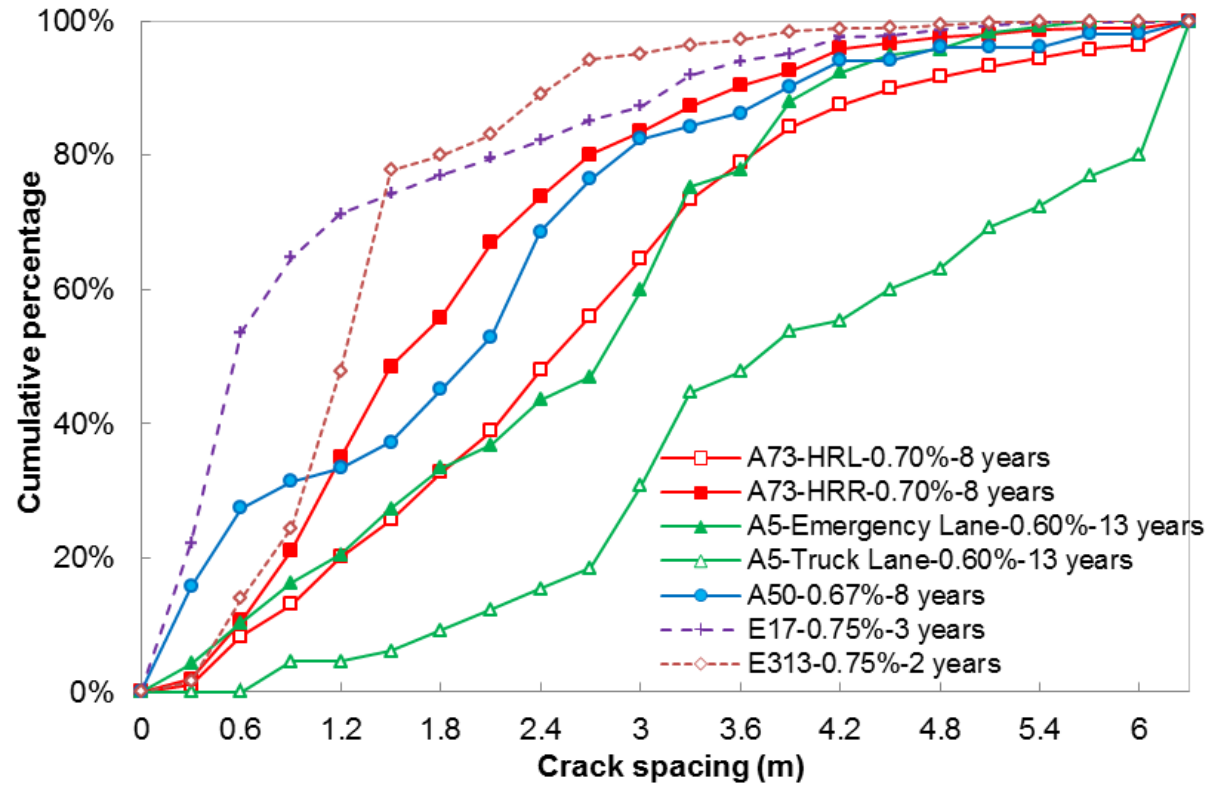
Crack width measurements not successful (filled with dust, a bit spalling)

A73 quite good performance:

- crack pattern (near to) optimal
- double tack coat between CRCP and PA
- polymer modified bitumen applied in both top layer and bottom layer of PA (normally only in top layer)
- few reflective cracks, no other damage
- no PA replacement needed in near future

Comparison crack spacings

Comparison of crack spacing frequency distributions: huge differences!



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