ACTIVE CRACK CONTROL FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS IN BELGIUM THROUGH PARTIAL SURFACE NOTCHES

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ABSTRACT

Recent field observations on several newly constructed Continuously Reinforced Concrete Pavements (CRCP) in Belgium have indicated that the crack pattern is characterized as low mean crack spacing (approximately 1.0 m after 2 years in-service) along with a high percentage of clusters of closely spaced cracks. Besides, field surveys also indicate that it is difficult to significantly reduce the probability of a non-uniform crack pattern, such as closely spaced cracks, meandering and Y-cracks, by slightly adjusting the amount of longitudinal steel. The non-uniform crack pattern is inevitable and common in conventional CRCP roads. Previous experiences in US have shown that active crack control for CRCP can eliminate the cluster cracks, and more uniform, crack pattern with straight cracks can be achieved. A new partial surface saw cut for active crack control was proposed and firstly adopted in the reconstruction project of motorway E313, Herentals, Belgium, 2012. This paper describes in detail the introduction of the proposed active crack control method. The effectiveness of improving the crack pattern is demonstrated by the results of field investigations.

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INTRODUCTION

In Belgium, Continuously Reinforced Concrete Pavements (CRCP) are being used on a large scale for more than forty years. The durability, the sustainability and the low maintenance of CRCP lead to long lasting applications in Belgium (*1*). However, the crack pattern still shows a cluster formation which may lead to punch-out development. According to field observations of several newly constructed CRCP under the current design concept in Belgium, the crack pattern is characterized as low mean crack spacing (approximately 1.0 m after 2 years in service) along with a high percentage of clusters of closely spaced cracks (*1~5*). The analysis of an extensive field and laboratory testing of 23 in-service CRCP roads in US has shown that the majority of punchouts occur in CRCP that have transverse cracks spaced from about 0.3 to 0.6m, and especially in clusters of closely spaced cracks (*6~7*). It should be mentioned that CRCP under current standard design concept behaves excellent and is hardly subjected to any deterioration, mainly due to the good support. However, occasional punchouts occur and therefore more research is needed to investigate how to obtain a more uniform crack pattern in CRCP.

The first method of reducing the non-uniform crack pattern may be achieved by optimizing the design or construction variables. In fact, the standard CRCP design and construction in Belgium underwent several changes over time with regard to longitudinal reinforcement rate, position of the steel layer, presence of an asphalt interlayer, pavement thickness, concrete mix, surface finishing and lane width. The field findings had indicated that these attempts can let the average crack spacing and mean crack width fall into a favorable range, but it is difficult to significantly reduce the probability of a non-uniform crack pattern, such as “Y” cracks and closely spaced transverse cracks, by adjusting the amount of longitudinal steel, primarily because of the variability of material properties, construction factors, and environmental conditions that are to some extent outside the contractor’s control (*5~6*).

An alternative solution is active crack control. Actually, it is not a new idea. Active crack control or induced cracking is being used extensively for concrete pavements, mainly in jointed plain concrete pavements (JPCP) and jointed reinforced concrete pavements. B.F. McCullough (*8~9*), D.G. Zollinger (*10*) and J. Roesler (*11*) had also adopted the idea of active crack control for CRCP. Their results of full scale field test sections have revealed that the active crack control technique achieved transverse cracks occurring sooner, straighter, and at the intended regular interval relative to the passive crack control, which can significantly reduce the probability of a non-uniform crack pattern and eventually prevent punchout development. However, there are still some limitations existing in the active crack control method applied in US. Firstly, the tape insertion method poses a difficulty during the construction period. Secondly, the presence of transverse saw cut through the whole width of the concrete slab may not only reduce the aggregate interlock and eventually decrease the load transfer efficiency, which will reduce the life of pavement, but also cause some surface defects, like spalling which could decrease the riding quality.

In 2012, Luc Rens proposed a modified active crack control method in Belgium attempting to achieve a better crack pattern, especially with the aim to reduce the number of closely spaced cracks. A partial surface saw cut active crack control technique was firstly applied in the reconstruction project of motorway E313 near the city of Herentals, Belgium. The objective of this paper is to present the development of the crack pattern of the new active crack control test section for CRCP.

REVIEV OF ACTIVE CRACK CONTROL ONCRCP

B.F. McCullough (1993) adopted active crack control methods on a large scale in four CRCP projects in Texas. The active method used in these projects included shallow saw-cut notches, metallic bar insertion. Field survey revealed that the transverse cracks occurred much sooner and straighter, with a reduced number of closely spaced cracks. He recommended active crack control if the CRCP is placed at an air temperature exceeding 32℃ and constructed with aggregates that have a coefficient of thermal expansion greater than 7.92×10^{-6} mm/mm/℃ (*8*~*9*).

As part of a study into the performance of different structural designs under accelerated load testing and to characterize the crack development, E. Kohler and J. Roesler (2004) constructed 10 full scale CRCP test sections at the Advanced Transportation Research and Engineering Laboratory in Illinois (*11*). On 5 sections the transverse crack induction method was applied. The active crack control process used two methods, early entry saw-cut and automated tape insertion. The early entry saw-cut began approximately 4 hours after concrete placement, and consisted of a shallow notch, 38mm in depth, on the top of the pavement over the full width. In the tape insertion method a 3 mm thick and 75 mm deep plastic tape was inserted in the fresh concrete. Induced crack spacing was set at 0.6, 1.2, 1.8 m for both crack induction methods. Regular crack surveys indicated that active crack control can significantly improve the uniformity of the crack pattern, i.e. more uniform, straighter, and early age transverse cracks were obtained. Besides, it was found that in the tape insertion method the cracks developed slightly earlier than in the saw cut method. At nearly all the saw cuts a transverse crack occurred, while on the other hand hardly any cracks occurred in between the saw cuts.

M. K. Lim (2009) studied the cracking process in a Portland cement concrete pavement by saw cutting method. Factors affecting efficiency of cracking predictable in PCC pavement consist of ambient temperature, depth of saw cut, timing of saw cut, location of the saw cut, and concrete mix and subgrade properties. He conducted tension slab tests in the laboratory to investigate the effects of the shape of the saw cut (“V” shape, square/circular shape, and rectangular shape with rounded edges), location of initiators, timing of saw cutting, depth of saw cut on the cracking predictable behavior (*12*).

The effectiveness of the active crack control method for a specific project is mainly dependent on the crack induction method, the timing operation, the layout of the crack inducers.

Early entry method

Early entry saws are lightweight devices which allow the sawing operation to begin as soon as 1 to 4 hours after concrete placement, depending on the concrete properties and weather conditions (*13*). In addition, most early entry saws use a dry-cutting operation with specially designed blades that do not require water for cooling. Early sawing is believed to increase the probability that the cracks will be induced at the sawcut location. Besides, because the pavement is being sawed earlier, the depth of the sawing needed to initiate cracking can be reduced (*14*).

Metallic/Plastic Insertion method

Single layer and double layers metallic have been inserted into fresh concrete to act as crack inducers in Texas’s studies (*8*~*10*). These crack inducers were intended to induce bottom-up cracks in the concrete. Crack surveys showed that early age saw cuts were more effective than the metallic insertion method for crack induction. In contrast, where the plastic tape was inserted in the top part of CRPC slab in the test section in Illinois (*11*), the field results showed that the cracks developed slightly earlier in the tape insertion method compared to the saw cutting method. It can be attributed to the location of the crack inducer. For the same the pavement surface reduction area, the crack inducer, intended to initiate cracks from the top part of the slab, is much more effective than that initiating cracks from the interior of the concrete, because the significant changes of moisture and temperature occurring at the surface of the slab help to initiate cracking.

Saw cutting timing

Timing is a very important factor in achieving the goal of crack induction, particularly at shallow saw cut notches. There is an ideal "saw-cutting window", as show in Figure 1. If the timing of the saw cutting operation is too early, raveling of the concrete will occur because the concrete has not yet developed enough strength to resist the saw machine. On the other hand, a too late saw cutting operation which may result in random cracking due to the buildup of residual stresses (*15*). The later time limit is of particular concern because the longer that sawing is delayed, the greater the chance that random cracking may develop (*16*).

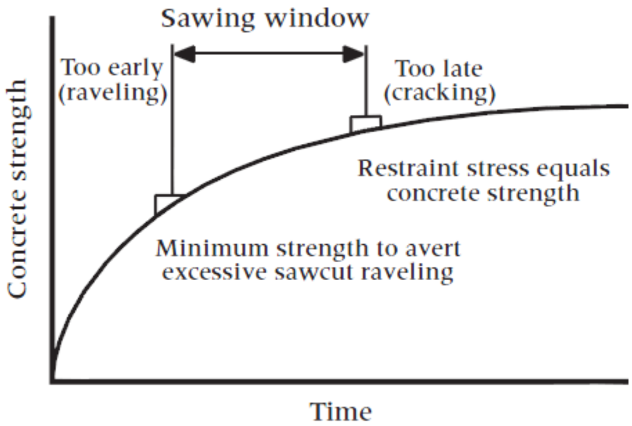


FIGURE 1 Concept of joint sawing "window" (Okamoto et al.1994)

Previous experiences with early age sawcutting have indicated that the notches should be made between the initial and final setting of the concrete. In general, the sawing should occur between 4 and 12 hours after paving (*8*), but this time frame will vary considerably depending upon the constituent materials, mix properties, external restraint forces and environmental factors.

In addition, the saw cutting operation should be done without impacting the conventional construction execution scheme. It should not pose a risk to increase the construction difficulty and decrease the construction progress. Exposed aggregate surface is common practice on Belgian CRCP motorways. In order to protect it against drying out, the concrete is covered with a plastic sheet as soon as the setting retarder has been applied. So the saw cutting is applied immediately after the removal of the plastic sheet, which is around10 to 24hours after concrete placement.

Saw cutting depth

In the case of JPCP, the conventional depth of joint sawing is often taken to be one quarter of the slab thickness for transverse contraction joints in AASHTO 1993 (*17*). The American Concrete Pavement Association suggested that the depth of the saw cut should be at least one-third of the slab thickness (*18*), which is common practice in Europe. However, considering the potential of corrosion of the longitudinal steel rebars, CRCP requires a sufficient concrete cover for the steel rebars, so the saw cut depth for active crack control in CRCP can not go as deep as that used in JPCP. Besides, D.G. Zollinger advocates that a shallow cut, usually at least 25mm, may be adequate if the sawing is done early enough. His argument is that the shallower saw cut takes advantage of the significant changes in moisture and temperature conditions at the surface of the slab to help initiate cracking below the saw cut (*14*). The standard position of the longitudinal reinforcement is above the middle of the slab. In general, the concrete cover over the longitudinal rebars amounts 80 mm. Therefore, the adequate depth of the saw cut in CRCP is within30 to 60 mm.

ACTIVE CRACK CONTROL TEST SECTIONS IN BELGIUM

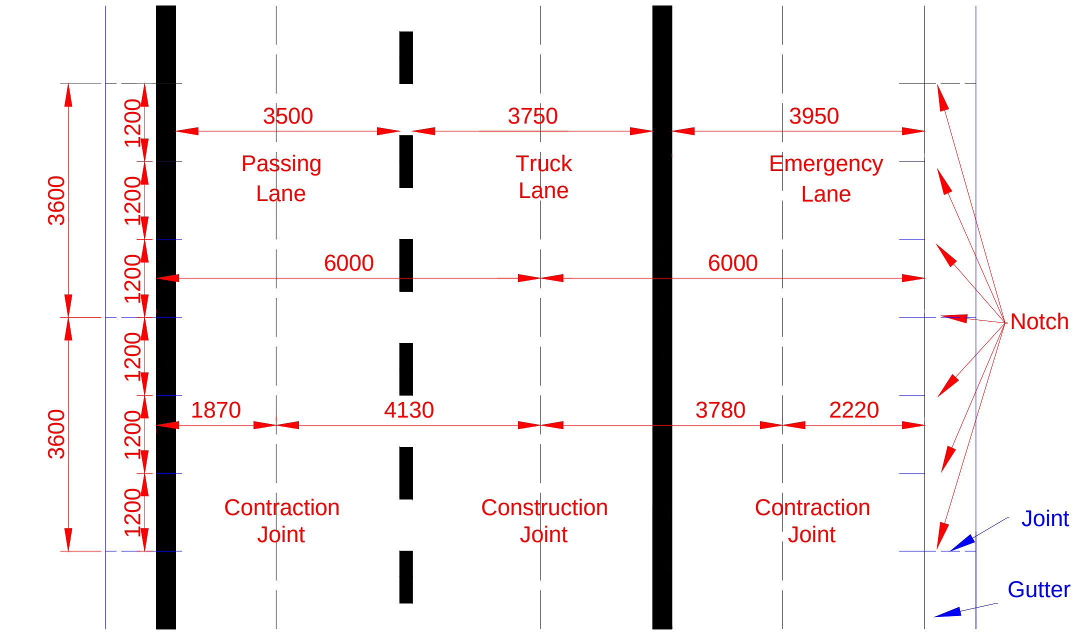
Inspired by an interesting finding during a field inspection of CRCP roundabouts in Belgium, Luc Rens found some transverse (radial) cracks looked like induced by the contraction joint of the adjacent inner circle of the roundabout. Besides, based on the American experiences of the shallow saw-cut notch method in active crack control for CRCP, he proposed a new active crack control procedure for CRCP that was firstly applied in the reconstruction project of motorway E313.

The reconstruction project E313 between Antwerp and Herentals was conducted in 2012, which is located approximately 24 km east of Antwerp. Figure 2 shows the layout of the test sections in E313, which was constructed according to the current standard practice in Belgium: 250 mm thick CRCP slab laid on a 50 mm bituminous inter-layer and a lean concrete base. The longitudinal reinforcing steel amounts 0.75%, and the position of the longitudinal steel reinforcement is about 80 mm below the pavement surface. Besides, due to the noise reduction requirement and economic considerations, two-lift construction was adopted for the concrete slab layer, the thickness of the top and the bottom layer is 50 mm and 200 mm, respectively.

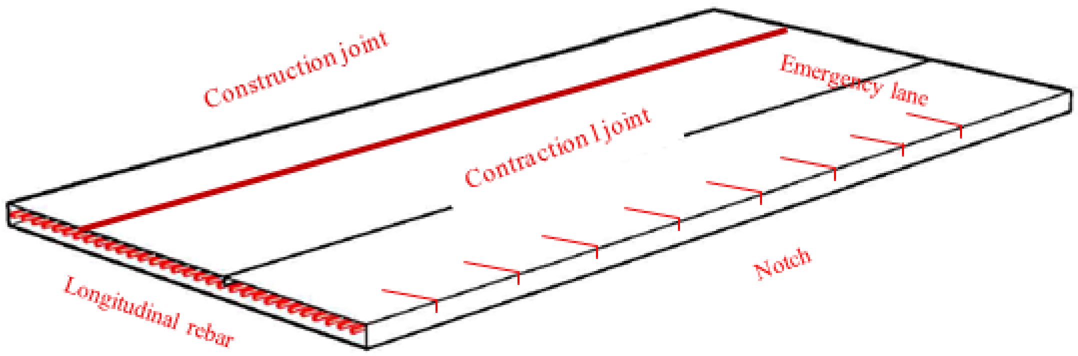
As shown in Figure 2, during the hardening of concrete partial surface notches were sawn on the outer side of the constructed slab, the length of the saw cut is 400 mm, the spacing is 1.20m.The cut was applied immediately after the washing out of the surface of the pavement, generally within 24 hours after concrete placement.

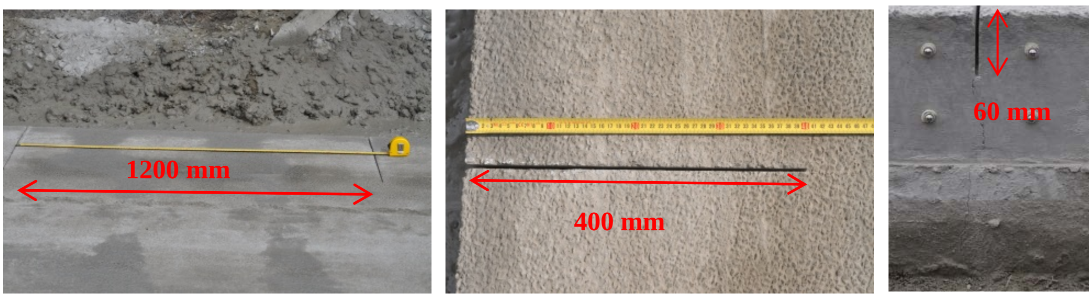
The E313 project contains two crack control test sections. During the first phase of this reconstruction project, the saw-cut depth is only 30 mm, which is around one eighth of the concrete slab thickness. The saw cut was done after the cutting of the contraction joint, so after approximately 24 to 36 hours. Subsequently, in order to evaluate the effect of the saw-cut depth on the effectiveness on the induced crack pattern, the depth was increased to 60 mm during the subsequent phase of this project. The time of saw-cutting was also earlier than in the first phase of the project, the saw-cut was applied immediately after the removal of the plastic sheet, generally within 24 hours after concrete placement.

One 500 m long test section at the outer lane with 30 mm depth saw-cut and a 1100 m long section also at the outer lane with 60 mm saw-cut has been chosen for regular crack surveys right from the placement of concrete to evaluate the crack progression in this active crack control method. The 500 m long test section with 30 mm saw-cut was constructed in July, 2012 while the 1100 long test sections with 60 mm saw-cut was constructed in September, 2012. After completion of the CRCP a jointed concrete gutter was constructed alongside the pavement.



(a) Schematic plan of the joints and lanes





(b) Schematic plan of the notch geometry

Units: mm

FIGURE2Layout of CRCP test section on E313

SURVEY RESULTS

Crack development time

Table 1 shows the effectiveness of the crack initiation on the test sections with different saw cut depths on the E313. For the 60 mm depth saw cut section, nearly all the cracks that occurred during the first 4 days, did occur at a sawcut, 21.3% of the saw cuts had propagated into a crack. This percentage rapidly increased to 61.9% about 2 months after construction. After that, the effects of saw cuts on inducing new cracks beneath the notch became small as the percentage increased to only 66.7% after the first winter. It indicates that this partial surface saw cut especially induces cracks beneath the notch during the very early age of the pavement which is normally within the first two months after construction. But after those two months, the saw cuts remain quite effective, as in the period between 65 and 204 days 43 of the new 97 cracks (i.e. 45% of the new cracks) occurred at a saw cut.

TABLE 1Percentage of cracks initiated at saw-cut notch

Section	Length (m)	Age (day)	Number of Notches (N1)	Number of Cracks (N2)	Number of Cracks at Notches (N3)	Effectiveness of the Notches % (N3/N1)	Percentage of cracks in category (%) Distance to nearest notch (m)			
							0	0-0.2	0.2-0.4	0.4-0.6
6cm	1100	4	897	193	191	21.3	98.9	0	0	1.1
	1100	65	897	664	555	61.9	83.5	2.4	7.7	6.4
	1100	204	897	761	598	66.7	78.6	3.8	9.7	8.2
3 cm	500	123	422	417	245	58.1	58.7	9.4	15.9	16.0
	500	262	422	497	281	56.5	56.5	8.7	17.5	17.3

As illustrated in Figure 3, the average crack spacing in the first 4 days for both the passive motorway E17 and active crack control motorway E313are all approximately 5.6 m. It should be mentioned that the temperature conditions which play a dominant role in the early age behavior of CRCP was slightly different for the two projects. The mean temperature and the temperature variation of the concrete in the active crack control section during the first few days were slightly lower than that of the passive crack control section. However, as the age of the pavements goes on, both the 30 mm and 60 mm active crack control sections cracks developed slightly faster than on the passive crack control section in E17. In addition, the cracking is much more predictable in the active crack control section. After the first winter on the section with 60 mm depth notches, 78.6% of the cracks were located at the induced saw cuts, while this value is slightly lower for the 30 mm deep saw cuts, 56.5%.It indicates that the deeper saw cut depth is more effective in initiating cracks at the design locations. It should however be noted that the saw cutting timing of the 60 mm notches was slightly earlier than that of 30 mm notches.

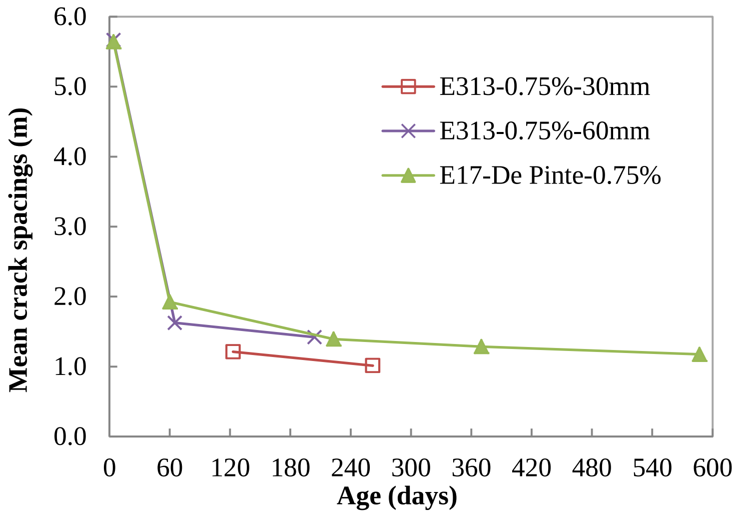
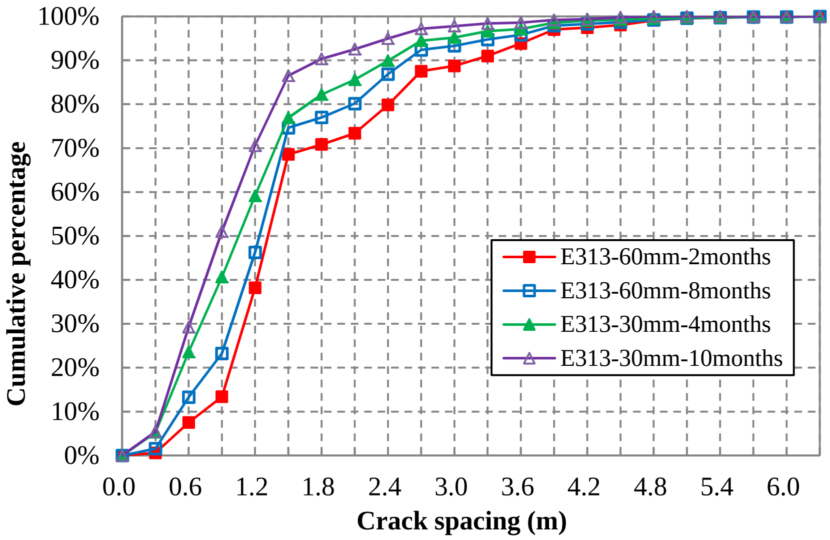


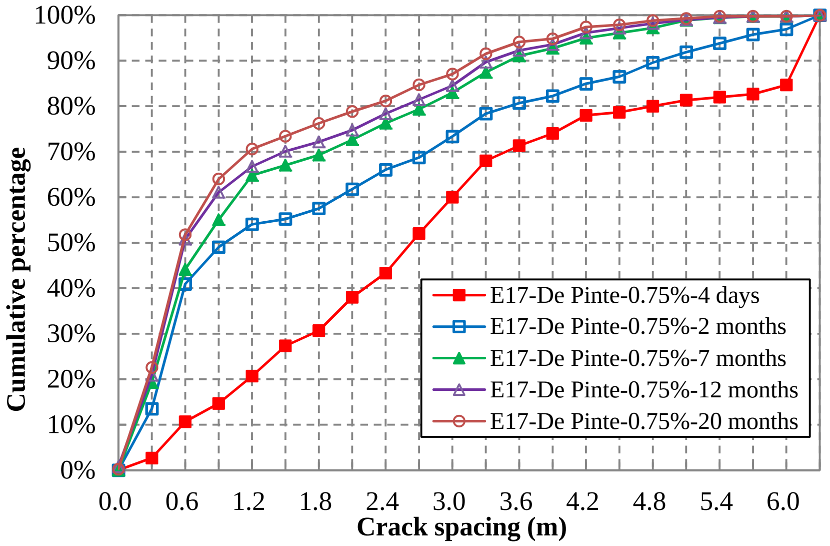
FIGURE3 Crack spacing development for active and passive crack control sections

Crack spacing distribution

Figure 4 compares the cumulative crack spacing distribution between passive and active crack control sections. Comparisons show that the saw-cut section on the E313 has a much better crack spacing distribution, as illustrated in Figure 4(a). The 60 mm notch section has less than 7.5% cracks spaced less than 0.6 m (short spaced cracks) approximately 8 months after paving. Besides, more than 80% of the crack spacing falls into the desirable range, 0.6 m to 2.4 m. In contrast, the passive crack control section on E17 has about 50% of the cracks less than 0.6 m 8 months after construction which is considered as an undesirable crack spacing distribution. Among the active crack control sections, the deeper the saw cut, the more uniform the expected crack spacing distribution. It should also be mentioned that a stable crack spacing pattern requires a complete environmental cycle which may be 1 to 2 years after construction due to the first year being mild winter temperature. The two recently monitored CRCP sections in Belgium both were constructed in fall and experienced a rather cold winter in 2012 and 2013, respectively. So it is reasonable to roughly assume that the short period crack spacing data will represent to some extent the crack behavior under the current design concept at long term.



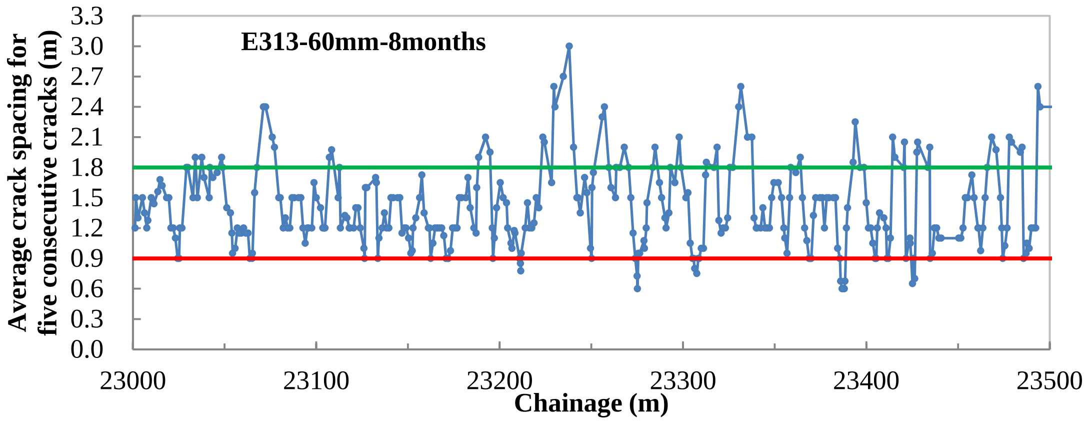
(a)



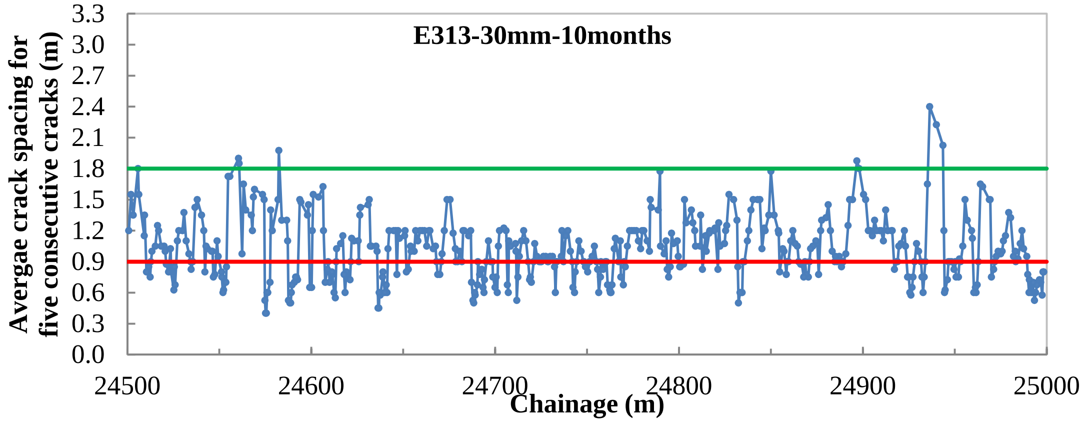
(b)

FIGURE4 Comparison of cumulative crack spacing distribution (a) E313; (b) E17

The uniformity of the crack spacing can also be indicated by the average spacing of five moving consecutive cracks. The average spacing of five moving consecutive cracks is not only useful in identifying the locations of clustered cracks (group of cracks with average cracks spacing less than 0.6 m) but also can be used to identify the extent of a pavement section that exhibits “acceptable” crack pattern. For example, the acceptable values of the average spacing of five moving consecutive cracks are assumed to be between 0.9 and 1.8 m (*6*, *10*). Figure 5 presents the comparison of the uniformity of the crack spacing on both active crack control test sections and the conventional passive crack control section. It is clearly shown that the crack pattern for the 60 mm saw cut section is much more uniform than the crack pattern of the 30 mm active crack control section and the passive crack control section.



(a)



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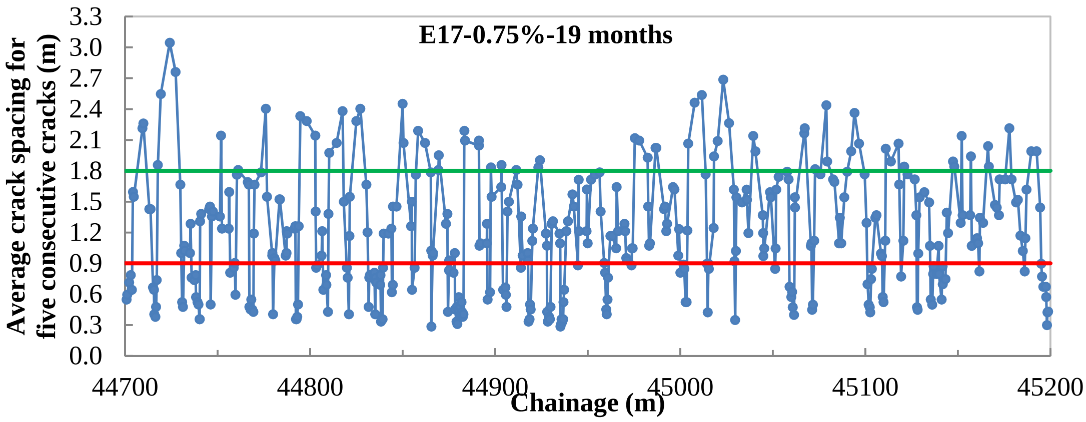


(c)

FIGURE 5 Average crack spacing distribution based on five consecutive cracks (a) E313, 60 mm deep saw cut; (b) E313, 30 mm deep saw cut; (c) E17, De Pinte, 0.75%

Cluster cracking

One typical crack spacing feature of CRCP under the current design concept is the high percentage of clusters of closely spaced cracks (*5*), as shown in Figure 6. Clustered cracks typically act as an indicator for punch-out development. The probability of two, three, four or five consecutive cracks occurring within a range of distances can be chosen as an indicator to evaluate the evidence of cluster cracking within a particular pavement segment (*10*).

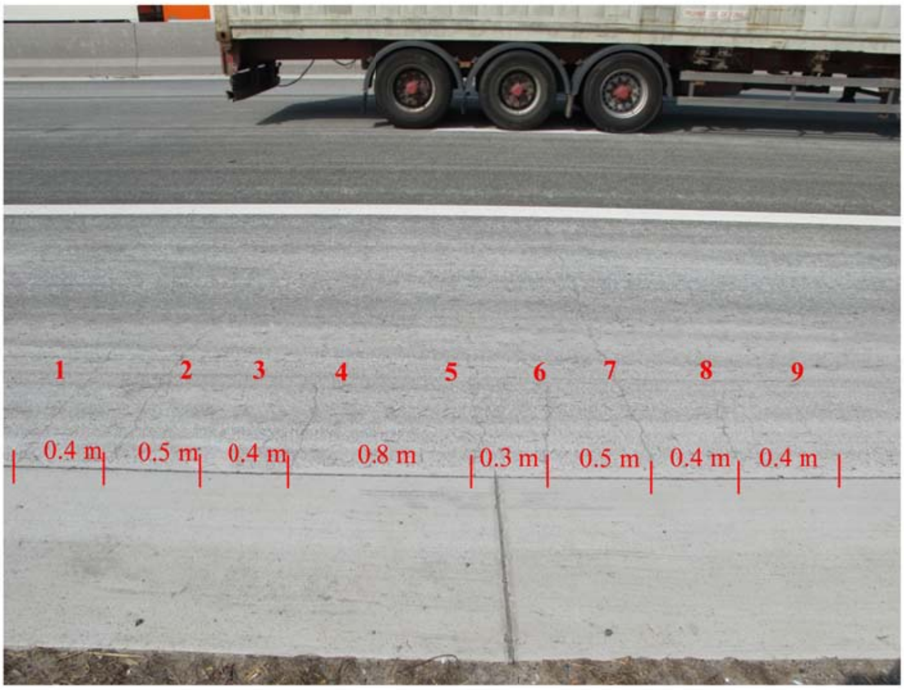


FIGURE 6 One cluster cracks in passive crack control section in E17

TABLE 2 Cluster cracking probability

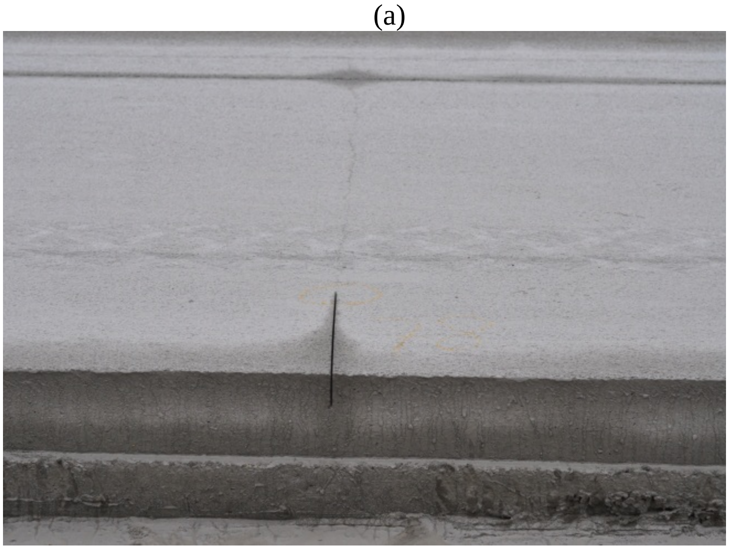
Road section	Age (days)	Reinforcement	PROB (2 Consecutive cracks, spacing< 0.6m)	PROB (3 Consecutive cracks, spacing< 0.6m)	PROB (4 Consecutive cracks, spacing< 0.6m))	PROB (5 Consecutive cracks, spacing< 0.6m)
E313-30 mm	123	0.75%	23.56%	6.75%	1.45%	0.48%
	263	0.75%	29.23%	14.14%	5.06%	1.62%
E313-60 mm	4	0.75%	0.00%	0.00%	0.00%	0.00%
	65	0.75%	7.52%	1.20%	0.00%	0.00%
	204	0.75%	13.27%	5.93%	1.98%	0.40%
E17-De Pinte	4	0.75%	12.50%	1.15%	0.00%	0.00%
	60	0.75%	40.93%	18.22%	7.78%	3.13%
	223	0.75%	44.13%	17.93%	7.58%	3.66%
	370	0.75%	50.77%	25.84%	12.44%	5.97%
	587	0.75%	51.76%	31.13%	16.55%	8.77%

Table 2 shows the cluster cracking probability of different numbers of consecutive cracks. The probability of cluster cracking of the active crack control test sections in E313 is much lower than the passive crack control section in E17. For instance, in the passive section E17, the probability of two and three consecutive cracks with a spacing less than 0.6 m of the section in E17 after 7 months is 44.13% and 17.93%, respectively, and subsequently increasing to 51.76% and 31.13% after 19 months. By contrast, both active crack control sections in E313 show much lower probability of two and three consecutive cracks less than 0.6 m at the same age of the pavement in E17. Among the active crack control method, the deeper 60 mm saw cut section shows a lower probability of cluster cracking compared to the 30 mm saw cut section.

Crack shape and crack face

The field surveys revealed that the passive CRCP section in E17 exhibited a fair amount of meandering, divided and Y-cracks, as shown in Figure 7(a). In contrast, there are no above-mentioned undesirable cracks in the 60 mm deep active crack control test section during the first 4 days after construction, and the 193 occurred transverse cracks are all perfectly straight as shown in Figure 7(b). However, the subsequent field surveys after 2 months and after the first winter indicated that the active crack control section exhibits lightly meandering cracks and occasionally divided cracks and Y-cracks, which indicates that the effect of these partial surface notches on the crack initiation is time dependent, and only sufficiently functioning during the first one or two months during the hardening period of concrete. Nevertheless, the survey also indicates that the randomness of the cracks is less than that occurred in E17.

(a)



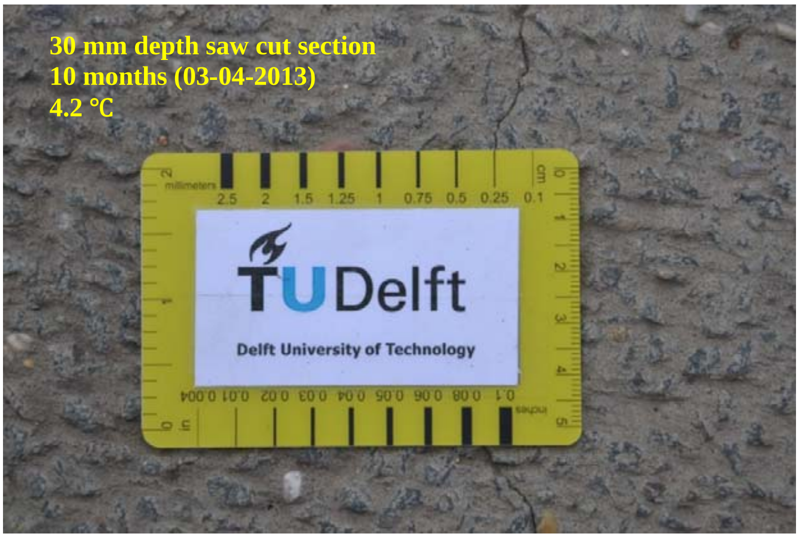
(b)

FIGURE 7 (a) Natural cracks, E17, 2 months after construction; (b) induced crack in the 60 mm deep sawcut section, E313, 2 days after construction

Crack width and crack movement

Crack width is a vital factor influencing the performance of CRCP. The crack width was measured inside the cracks at some depth (1 to 3 mm) below the pavement surface. Meanwhile, the concrete pavement surface temperature was also recorded.

Table 3 shows the crack width periodically measured by a microscope on the pavement surface. As can be seen in Table 3, the measured average crack width on the pavement surface of E313 was approximately 0.15 mm at an average pavement temperature of 20℃, and around 0.22 mm at an average pavement temperature of 6.0℃. The crack width on the passive crack control section on the E17 is on average slightly larger than on the active control section on the E313. The cracks on the surface are relatively wider than expected. In order to obtain the horizontal crack width variation due to temperature variation, a procedure was adopted to accurately measure the horizontal crack width change by a linear variable differential transformer (LVDT) on steel studs glued at the edge of the pavement at either side of the crack (*4-5*). The daily crack movement at the pavement surface during summer condition, within 4 days after construction, varied from 0.0 to 0.15 mm.



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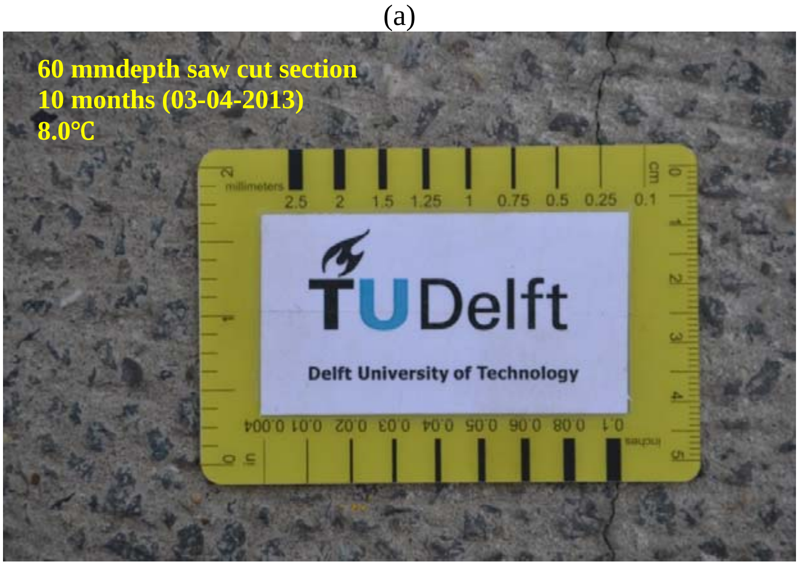

(b)

FIGURE8 Crack width on the pavement surface of E313 (a) 30 mm saw cut section; (b) 60 mm saw cut section

TABLE 3 Crack width on the pavement surface measured by microscope

Section	Percentage of reinforce-ment	Season	Temperature of pavement surface (°C)	Number of cracks	Crack width (mm)			
					Mean	Max.	Min.	Stdv.
E17 De Pinte	0.75%	Summer	30.3	8	0.169	0.22	0.10	0.036
	0.75%	Winter	2.2	10	0.312	0.35	0.19	0.087
E313 30 mm	0.75%	Summer	-	-	-	-	-	-
	0.75%	Winter	4.2	11	0.232	0.32	0.13	0.044
E313 60 mm	0.75%	Summer	20.5	17	0.152	0.31	0.10	0.032
	0.75%	Winter	8.0	12	0.201	0.27	0.14	0.034

SUMMARY OF FINDINGS AND CONCLUSIONS

Recent field observations on several newly constructed CRCP in Belgium have indicated that the crack pattern is characterized as low crack spacing along with a high percentage of clusters of closely spaced cracks. Besides, field surveys also indicate that it is difficult to significantly reduce the probability of a non-uniform crack pattern, such as closely spaced cracks, meandering and Y-cracks, by slightly adjusting the amount of longitudinal steel. The non-uniform crack pattern is inevitable and common in conventional CRCP roads, but may lead to punchout development. In order to eliminate the non-uniform crack pattern, a new partial surface sawcut for active crack control was proposed and firstly adopted in the reconstruction of the motorway E313 near the city of Herentals, Belgium, 2012. The length of the saw cut was 400 mm rather than the entire width of the pavement as applied in the US active crack control sections. The interval between two notches was 1.20 m, and two saw cut depths were used in this project, 30 mm and 60 mm, respectively. Based on regular field investigations of the test sections, following conclusions can be drawn.

The partial surface saw cut can indeed initiate cracks beneath the notches: around 20% of notches propagated to cracks after 3 nights, subsequently increasing to approximately 60% after 2 months. The effect of this active crack control method is however time dependent, it is especially efficient within the first two months after construction.

This active crack control method can significantly decrease the percentage of short spaced cracks and cluster cracks. Field investigations revealed that the cracks were much straighter and uniform for the active crack control section.

Saw cut depth and saw cut time influence the effectiveness of crack induction in this active control method. A larger saw cut depth and earlier saw cutting after concrete placement can help to induce cracks at the notches.

The crack widths for the active crack control section were slightly smaller than those on the passive crack control section. The crack width measurements will be repeated in future to verify this provisional conclusion.

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