EVALUATION OF LONGITUDINAL EVENNESS OF A NEWLY CONSTRUCTED ROAD SECTION: A DETAILED STUDY OF DIFFERENT EVENNESS MEASUREMENTS

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ABSTRACT

The requirements for longitudinal evenness of newly constructed road surfaces in Belgium are expressed in the "Evenness Coefficient" (EC) defined as half of the surface between the profile as obtained from measurements with the "Analyseur de Profil en Long" (APL) and a curve representing the "ideal profile" calculated by a sliding average method. Requirements can be expressed in the gap height measured with the "three-metre straightedge" (TMS) but the acceptance of road works is often based on APL data.
When requirements are not matched, the contractor must improve the longitudinal evenness after road works completion. Contractors and road administrations want to exploit APL data fully.
This contribution discusses the finesses of longitudinal evenness measurements using APL, EC and TMS. A case study illustrates to what extend the APL data can be exploited. A road section with high unevenness was investigated by APL and TMS, and the geometrical unevenness of the road surface was measured point-wise by elevation measurements in the wheel paths on 8 sub-sections of the road. The case will confirm that a theoretical estimate of TMS gap height from APL data is realistic and will show rare influence of crossfall variation on the APL.

1. INTRODUCTION: CONTEXT AND OUTLINE

The requirements for longitudinal evenness of newly constructed road surfaces in Belgium are often expressed in the "Evenness Coefficient" (EC). When the requirements demanded by the road administration are not matched, the contractor is to perform additional works at his own expense in order to rectify the situation. Improving the longitudinal evenness of a road surface after road works completion is a very difficult practical problem. The contractor would look for the optimal solution improving the evenness of the road. Contractors and road administrations therefore are very interested in exploiting the available EC data in their decision making process.

Also at the European level the possible uses of different indicators for road evenness are as many topics for research activity. The technical committee TC227 "Road Materials" of the European Committee for Standardization (CEN) and its working group WG5 on "Surface characteristics" did publish a norm on the measurement methods (EN13036-6:2008, [1]) but is still preparing a norm on the indicators (prEN13036-5, [2]). The work presented in this contribution is also a preparatory study in the frame of a pre-normative research project (contract reference: CC CCN/PN/NBN-708) supported by the Belgian Bureau for Standardization (NBN) on indicators of longitudinal evenness.

In Section 2 an overview of the measurement devices and techniques will be given that are relevant to the study presented in this contribution. Also, the definition and some properties of the indicators used here will be given. In Section 3 a theoretical computation that allows interpreting the EC as an estimate of the "height" of the unevenness of the road will be discussed. A case study will be presented in Section 4, describing the situation on a particular road, the measurements that have been done and the conclusions from different comparisons on the collected measurement data. In Section 5 the investigations done in the frame of the presented case study will be put in the wider perspective of deeper insight in the EC indicator and its meaning for practical use.

2. MEASUREMENT TECHNIQUES, EVENNESS INDICATORS AND REQUIREMENTS

In Belgium the EC is measured using the device called “Analyseur de Profil en Long” (APL, developed by LCPC in France) when the EC is used as a requirement for recent road works. For the interpretation of the APL data it is important to have clear insight in the definition of the EC and in the functioning of the APL as a filter for some wavelengths in the road profile. In this Section we discuss in depth the finesses of the longitudinal evenness measurements with the APL, the EC indicator and the “three-metre straightedge” (TMS).

2.1. TMS

The standard tender specifications used in Belgium allow both APL and the TMS method ([3], [19]) and follow the method prescribed by the European norm ([4]). The TMS is a 3m long beam that is placed in any orientation on the road. The largest vertical opening under the beam is measured with a wedge. Oriented in the traffic direction, the beam is a means for the determination of longitudinal evenness at a particular point. The TMS method is slow and hinders traffic, and therefore not used as a systematic control method after road works. However, the contractor can easily execute this measurement during road construction.

2.2. APL

The APL is a device on a trailer towed by a car. Usually, two trailers are used at the same time, each in one of the wheel paths as described in [7]. The measurements are done at a constant speed. The wheel of the trailer is mounted on a pivoting arm. The APL is also equipped with an inertial pendulum giving a continuous horizontal reference. The wheel follows the unevenness of the road surface, the vertical movements of the wheel result in angular travel of the pivoting arm and an angular displacement transducer associated with the pendulum produces an electrical signal that is amplified and recorded. The chassis of the trailer is linked to the towing vehicle by a universal-jointed hitch, as to avoid all influence of the movements of the towing vehicle. In the case study we seem to have identified an exceptional situation in which the towing vehicle had some influence on the measurements.

The bandwidth of the APL signal is in the frequency range from 0,4Hz to 20Hz. At constant speed V (expressed in m/s), the detected wavelengths are in the interval [(V/20)m ; (V/0,4)m]. The method of measurement for APL (see [5], [7]) prescribes different constant speeds: 72km/h, 54km/h and 21,6km/h. In this way, the APL filters out very short and very large wavelengths in the road profile: at V = 6m/s, the APL registers a “profile” only taking into the range of wavelengths between 0,3m and 15m.

2.3. The family of indicators “EC_B”

The EC is a family of indicators: the $EC_{2,5m}$ (B=2,5m) mainly evaluates short wavelengths in the longitudinal road profile, EC_{10m} (B=10m) mainly evaluates waves of moderate lengths, and VC_{40m} (B=40m) mainly evaluates long wavelengths.

In the case of measurements with the APL, the evenness coefficient is computed from a profile represented by a large number of consecutively stored measurement points. First, the sliding average is computed: a fixed number of consecutive points is averaged and the consecutive averages form a new and smoother curve.Then the area between the two curves is computed as the sum of the areas of small vertical blocks over a chosen distance E.

From a theoretical point of view (see [6], available in Dutch or French) the wavelengths λ for which $B < \lambda < 4.B$ holds, contribute in a significant way to the value of EC_B. The choice of length E is only appropriate if $E > 2,5 . B$.

The definition of the evenness coefficient combines two operations:

- The sliding average technique – which introduces a filter, and
- The integration over a block of length E between two distance markings on the road profile.

The constant speed at which the measurements can be performed depends on the requested wavelength interval. Table 1 gives an overview of the correspondance between speed and wavelengths for the most frequent measurement conditions for the APL.

Measurement speed		Wave length Interval (m)
(km/u)	(m/s)	
21,6	6	[0,2 ; 15]
54	15	[1,0 ; 30]
72	20	[1,0 ; 40]
144	40	[1,4 ; 100]

Table 1 – speed and wave length rate

Another way of presentation is given in Table 2.

Basis B (m)	Speed (km/h)	Block length E (m)
1,25	21,6 ; 54 ; 72	10 ; 25 ; 100
2,5	21,6 ; 54 ; 72	10 ; 25 ; 100
10	21,6 ; 54 ; 72	25 ; 100
15	21,6 ; 54 ; 72	100 ; 200
40	72	100 ; 200 ; 400

Table 2 – size of basis implies speed and block length

When the EC with basis B is requested, only some block lengths E are allowed and the measurements must be performed at a certain constant speed.

2.4. Usual Evenness Requirements for Road Works in Belgium

The requirements on the evenness measured by APL and expressed in EC depend on the type of roads: main roads, primary roads and secondary or local roads. The requirements differ also per region. As an example, Table 3 gives the overview of requirements in Flanders: the measured values must be lower than the values in the table. The hereafter discussed case study is a local road located in Flanders. Since the maximal allowed traffic speed in the lowest on secondary and local roads, there is no requirement on EC_{40m} on such type of roads.

Basis B (m)	Block length E (m)	Acceptable upper bounds for EC_B on block with length E (in 1000 mm^2/hm)		
		Main roads	Primary roads	Secondary or local roads
2,5	25	35	40	45
10	100	70	80	90
40	400	140	160	-

Table 3 – requirements in Flanders (according to [5])

2.5. Other indicators and measurement devices

The evenness on Belgian regional roads is monitored regularly. A map of the data combined with other surface characteristics is used for pavement management. In Wallonia this is done with the APL but in Flanders the laser technique of the ARAN is used instead. The bandwidth of wavelengths mesured with the ARAN is [0,25m ; 90m] and differs from the APL bandwidth. Hence, the profile recorded by the ARAN differs from the profile recorded by the APL. This also translates in differences when computing the EC_B from ARAN or APL profiles. The road administration in Flanders uses a correlation factor determined by experience. The best correlation is available for EC_{10m}, whereas for EC_{40m} and $EC_{2,5m}$ the presence of different wavelengths in the bandwidths interfers. In all cases the EC_B measured by the ARAN is somewhat bigger than the one measured by the APL. For an evaluation on the requirements recently executed road works only the APL is used.

Professionals in Belgium measuring longitudinal unevenness follow the evolution in the use of other indicators in other countries, and in particular the indicators “NBO”, “IRI”, “WLP” and the “evenness number” obtained from the “PSD”.

The “Notes par Bandes d’Ondes” (NBO) is a family of three indicators: PO (small wavelengths), MO (moderate wavelengths), GO (large wavelengths). The NBO is computed from the profile measured and registered by the APL (see also [7]).

The International Roughness Index (IRI) is an indicator based on the simulated response of a generic vehicle on the unevenness of the road surface. The model of the generic vehicle is called the “quarter-car”. A comprehensive explanation can be found in [8]. Even if the IRI was well-studied in the USA and by the World Bank (see [9], [10]) the IRI is still subject of research, as reported in [11] for instance.

The indicator called “weighted longitudinal profile” (WLP) is deduced from the spectral decomposition PSD. The WLP was developed at the university of Aachen, Germany (see [12]) and also studied in Austria (see [13]).

The PSD was already used for the evaluation of longitudinal unevenness and described in the ISO standard 8608. The decomposition in spectral waves was also studied at the BRRC as reported in [14] and [15]. An interesting article with literature review is [16].

A database of indicators used in Europe and beyond, including indicators for longitudinal evenness was established during the COST action 354 (see [17]). Efforts for harmonisation of measurement devices and indicators for evenness were made in the past, as reported in [18].

3. THEORETICAL COMPARISON BETWEEN EC_B AND TMS

In BRRC report [6] a theoretical, analytical computation is presented, giving a better understanding of the meaning of the values of the evenness coefficient. We revisit this computation here since it played a role in the case study described below.

The computation starts from a road profile that is represented by the ideal sinosoidal signal given by the formula: $A \cdot \sin(2 \pi x / \lambda)$. Obviously, this is a purely theoretical hypothesis, since in reality a measured and registered road profile will never have such a simple shape. But in the case of the ideal sinosoidal signal, the EC_B can be computed in an analytical way (by the computation of integrals under functions described with mathematical formulas). This results in the following analytical expression for EC_B in the case of a sinosoidal road profile:

$$EC_B = (100 \cdot A / \pi) \cdot (1 - (\lambda / \pi.B) \cdot \sin(\pi \cdot B / \lambda)).$$

The factor 100 is a scale factor, the block length E is of no importance in the case of a sinosoidal road profile as long as E is a multiple of λ. For a continuous function such as a sinosoidal input signal, the evenness coefficient is equal to the average of the difference between two continuous functions: the input signal and the sliding average.

For the sinosoidal input signal, the maximal deformation with respect to a straight beam placed on the curve is equal to 2.A – two times the amplitude of the signal.

This formula also indicates that the wavelengths λ between B and 4.B contribute in a significant way to EC_B. Obviously, the profile measured with the APL will never be an ideal sinosoidal signal and therefore all wavelengths λ between B and 4.B will contribute in some extent to the value obtained for EC_B.

The analytical formula for EC_B allows estimating the vertical deformation of the road surface with respect to a beam of “B” metre long. The measurement with the “B-metre straightedge” only takes into account the wavelengths λ smaller than B. For a value of λ between B/2 and B, $\sin(\pi.B/\lambda)$ is smaller or equal to 0. A sinosoidal signal with a value for EC_B, will have an amplitude A slightly overestimated by the formula $A = \pi / 100 \cdot EC_B$, if $B/2 \leq \lambda \leq B$. For a value of λ between 0 and B/2, $\sin(\pi.B/\lambda)$ is greater or equal to 0. A sinosoidal signal with a value for EC_B, will have an amplitude A slightly bigger than the value given by the formula:

$$A = \pi / 100 \cdot EC_B.$$

A simple computation allows us delimiting the value of A in the following way:

$$A < \pi / 100 \cdot EC_B. (2. \pi/(2.\pi-1)).$$

The multiplicative factor $2. \pi/(2.\pi-1)$ is almost equal to 1,2.

In the case of measurements on the road, the smallest wavelengths will not contribute to the evenness coefficient because of the step size with which the profile is registered by the computer. The small wavelengths contributing to EC_B will have a very local influence. Therefore we can ignore the small wavelengths and by doing so we know that in the worst case we underestimate the amplitude with 20%.

Under this condition, we can use the following formula for estimating the opening H under the “B-metre straightedge” starting from a sinosoidal input signal with $\lambda = B$:

$$EC_B = (100 . A / \pi), \text{ where } H = 2.A, \text{ and hence: } H = 2. \pi / 100 . EC_B.$$

Using this formula for B=2,5m, we conclude with the following statement:

§ The maximal theoretical opening H expressed in mm under a virtual “B-metre straightedge” beam positioned in the longitudinal direction on any place within a block of length E=10m and for a value of $EC_{2,5m}$ expressed on the block of E=10m is given in Table 4.

$EC_{2,5m}$ in 1000mm^2/hm	10	30	50	70	90	110	150	180
H (=2.A) in mm	0.63	1.89	3.14	4.40	5.66	6.91	9.42	11.31
H + 20% in mm	0.76	2.27	3.77	5.28	6.80	8.30	11.31	13.58

Table 4 – Theoretical estimate of unevenness from $EC_{2.5m}$

4. A CASE STUDY

The case study in this section presented itself as a classical request for quality control after road works on a communal local road ([20]). The case turned out to be particularly interesting – also in the frame of the pre-normative research – for further and deeper investigations, not only based on APL measurements but also on TMS and level point measurements and the comparison between the obtained measurement data.

4.1. Site, local situation and problem

The in this case presented road section was a reconstructed road with one lane in each direction, connecting two villages. On several locations traffic islands were added, dividing the traffic lanes for traffic in opposite directions from each other. For this, the lanes were locally diverted sideways from the original straight road trace. The sideway shift of the lanes introduced bends at the beginning and at the end of the traffic islands as well as local changes in cross fall. The bicycle path on one side and the ditch on the other side of the road were not moved. They indeed were located far enough in order to redesign the local shifts at the new traffic islands but they also represented constraints on the execution of the road works.

Local authorities had the impression that the longitudinal evenness did not match the ruling standard tender specifications. Therefore they asked BRRC to measure the EC_B with the APL. These were executed on the 13th of December 2010.

4.2. Initial APL measurements and visual inspection

From the measurements with the APL and the visual inspections it became already clear that the execution of the road works did not match the requirements as expressed in the standard tender specifications ([5]). Using the theoretical estimate for opening H under a virtual “B-metre straightedge” for B=2,5m and B=10m, we obtained the values given in Table 5. Obviously, a larger block length of E=25m instead of E=10m flattens extreme values and the range of values for $EC_{2,5m}$ is therefore more reduced for E=25m.

EC type	EC-values based on APL measurements	Theoretical opening H
B=2,5m, E=10m	from 20 to 105 (one value = 157)	1 to 8 mm (2,5m straightedge)
B=2,5m, E=25m	From 45 to 80	3 to 6 mm (2,5m straightedge)
B=10m, E=100m	from 135 to 185	8 to 11 mm (10m straightedge)

Table 5 – Theoretical estimates for case study site

The contractor wanted to know if the APL measurements could give an indication about the locations where the unevenness was insufficient and how these unevenness could be corrected by localized repairs only. The contractor also argued that the measurements could be influenced by the variation of the cross fall near the traffic islands, which could result in overrated EC-values at these spots.

4.3. A "proof of excellence" for the APL?

The local authorities had asked a topographer to map the road surface. These measurements allowed concluding that near the beginning and the end of some of the traffic islands, large level variations are present: up to 7mm height difference was reported on a mere distance of 0,5m. This fluctuation was not present on the side, along the bicycle path.

The topographer had followed the center line of the road between the traffic islands and switched to the center line of each of the lanes in the short subsections next to the traffic islands. This did not correspond at all to the lines on which the APL had measured the evenness since the APL measures in the wheel paths on each of the lanes. Therefore, in order to demonstrate that the APL measurements did really represent important local unevenness, some additional measurements were performed on the 11th of May 2011. At 8 different locations, all near the beginning or the end of a traffic island, a BRRC team set out two lines aiming to correspond as much as possible the wheel paths where the APL had measured before. Then, at intervals of 1m, both TMS and level point measurements were performed. The TMS was measured aligned with the line drawn on the road surface, in line with the wheel paths. The level point measurements were made with respect to the first point on each of the sub-sections, thus giving an image of the relative change in height along the drawn wheel paths. All these results were then compared to each other and to the profiles and EC_B values obtained from the APL.

4.4. Comparative results for this case

The results of TMS and level point measurements were consistent with the results of the topographer, which comforts us on the quality of the BRRC measurements.

The level point measurements indicate that at some places a transition takes place from a "saddle" profile to a slope profile oriented to one of the sides only. These transitions are never smooth: they are executed with several successive discontinuities with variations both in longitudinal evenness and in cross fall. The variation of the cross fall was deduced from the level point measurements. These indicate that the cross fall indeed varies but not in a monotonous way, as illustrated in Figure 1. The combination of strong variations in longitudinal evenness and in cross fall could have had some influence on $EC_{2.5m}$ values computed on blocks of E=10m long.

A further comparison between EC_{10m} and TMS could not be made since the sub-sections inspected with TMS were too short (about 25m long only). However, large but local variations in longitudinal evenness and cross fall will have very limited effect on EC_{10m} averaged over blocks of E=25m or E=100m long. Peaks in the values for EC_{10m} cannot be attributed to smooth transitions in the cross fall.

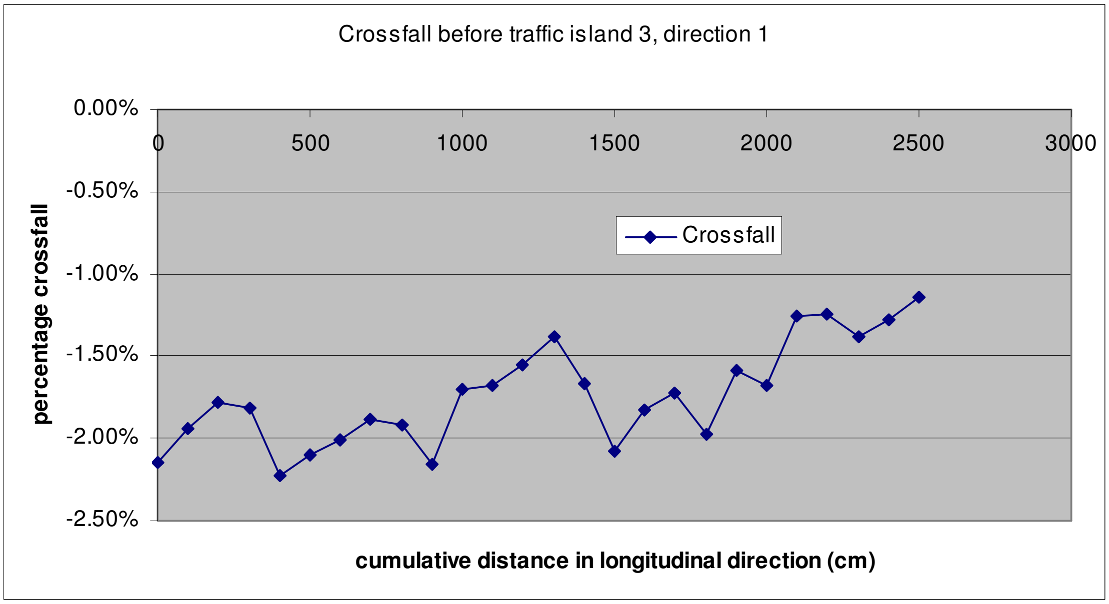

Figure 1 – cross fall varies a lot

The TMS and level point measurements did not give any indication that the variations in cross fall, the local variations in longitudinal evenness at the beginning or the end of the traffic islands, or the presence of very short bumps would have a significant influence on the APL measurements. Rather, the large values obtained from the APL measurements at the beginning or the end of the traffic islands could be explained by the actual presence of bumps at these places.

From the profile measured with the level point measurements the $EC_{2,5m}$ was computed. The level point measurements gave level values with a 1m gap between two consecutive points on the wheel path. First intermediate level values were computed by interpolation and with step size of 0.05m. Then this profile was used as a start for the computation of the $EC_{2,5m}$ on blocks of length E=10m. These were compared to the values for $EC_{2,5m}$ on blocks of length E=10m obtained from the APL measurements at a constant speed of 21,6km/h. The comparison was difficult for several reasons: the wheel tracks used for the level point measurements probably do not completely match the wheel tracks where the APL passed and the correspondance between locations in the longitudinal direction of points measured with the two very different measurement techniques is difficult to establish. Also the level point measurements are differently sensitive to wavelengths present in the road profile, from which we can expect that the profiles will never completely match. However, the general tendancies do match when put on one graph as in Figure 2.

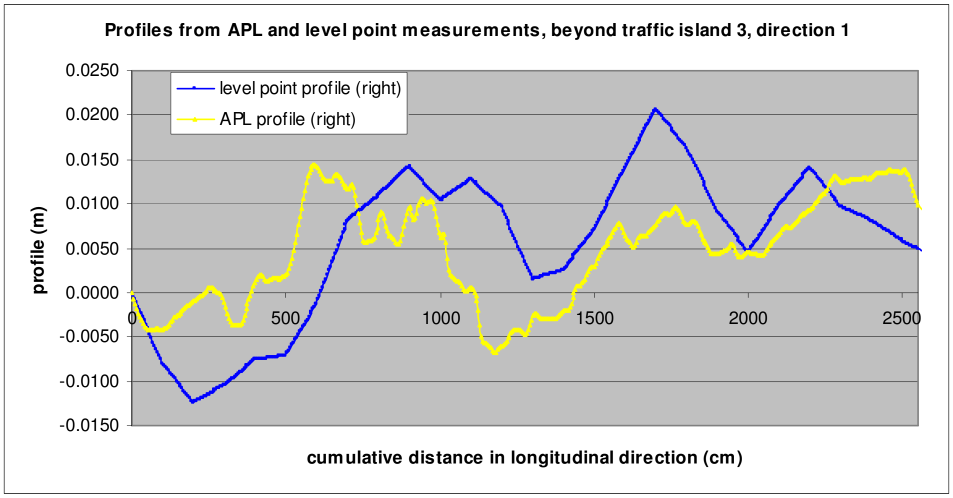

Figure 2 – Comparison between profile of APL and level point measurements

Since these profiles compare rather well, the evenness coefficients computed from these profiles are similar too. In direction 1 the APL measurements seem to give some overrating of $EC_{2,5m}$ with respect to the values obtained from the level point measurements, as shown in Figure 3. This could partially be due to the different sensitivity on wavelengths: level point measurements flatten the profile up to wavelengths of λ=1m.

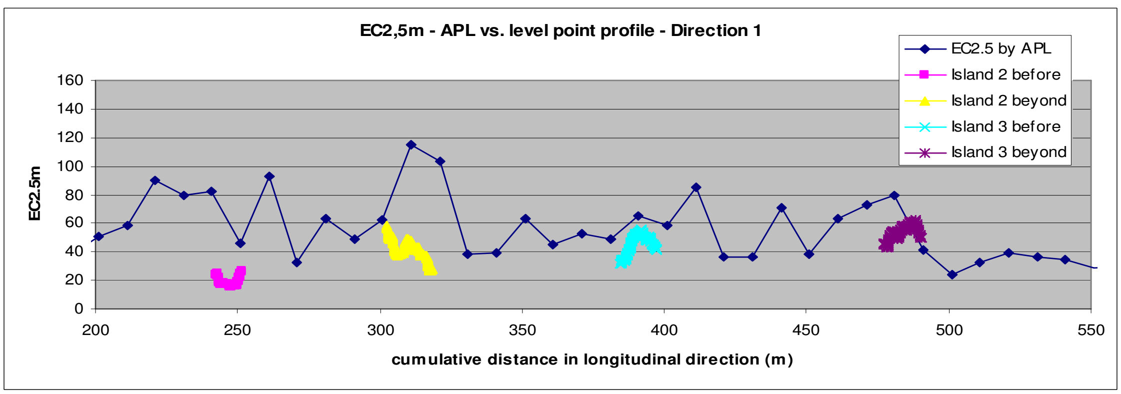

Figure 3 – EC comparisons (direction 1)

In the opposite (second) direction the $EC_{2,5m}$ obtained from APL and level point measurements match very well, as illustrated in Figure 4.

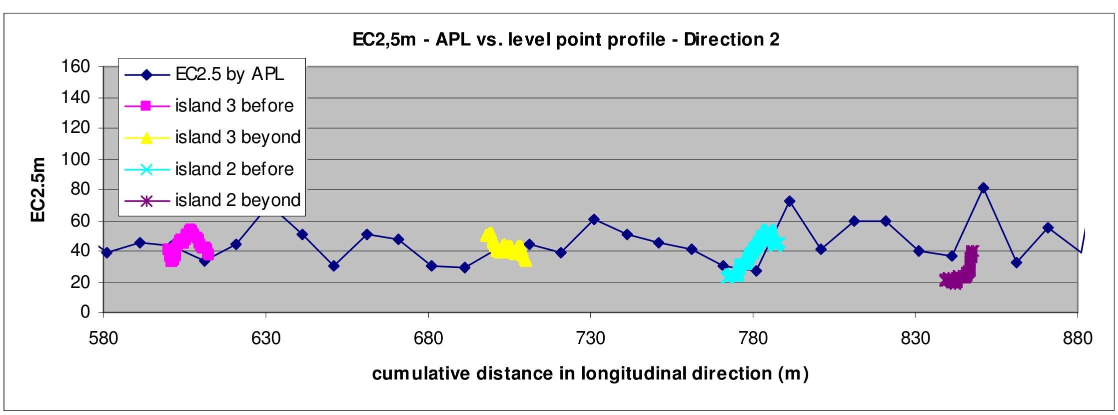

Figure 4 – EC comparisons (direction 2)

As indicated with the theoretical estimate of height opening H under a virtual "B-metre straightedge" from the APL measurements, the TMS measurements on all sub-sections showed the presence of important unevenness. The estimates from APL measurements for B=2,5m are indeed comparable with the measurement results of the three metre straightedge method. Between consecutive points measured with TMS near the traffic islands, the unevenness varied from 0 to 10mm and on several places the height under the TMS beam was more than 10mm, which is more than precisely measurable with the wedge of the TMS device. Hence, the estimate from APL data appeared to be realistic.

We tried to compare the TMS data and the APL height estimate pointwise, as illustrated by Table 6. For each of the eight locations near the different traffic islands, Table 6 presents the points that allowed a comparison. Of course the same difficulties arise as with the pointwise comparison between APL and point level measurements. Nevertheless, the comparison produced consistent results with small deviations that could be attributed to small shifts between the exact locations where the compared data were collected, both in longitudinal and in transverse direction.

location of the measured points				right wheel path			left wheel path			
position n°	direction n°	island n°	before (b) or beyond (a)	TMS (mm)	point level difference (mm)	EC2.5m (APL)	TMS (mm)	point level difference (mm)	EC2.5m (APL)	Crossfall
9	1	3	b	3.5	1.0	65.4	0.0	0.5	60.3	-1.92%
19	1	3	b	4.0	0.8	58.7	2.0	-2.5	56.2	-1.97%
6	1	3	a	4.0	0.5	79.4	6.0	0.8	76.8	-1.07%
16	1	3	a	2.0	4.6	41.1	2.0	2.7	28.8	-1.74%
26	1	3	a	1.5	-2.3	24.2	2.0	-1.0	26.6	-1.87%
1	1	2	b	3.5	0.0	82.4	3.5	0.0	59.0	-2.26%
11	1	2	b	2.5	-5.1	46.3	2.0	-1.7	33.3	-1.03%
21	1	2	b	> 10	-10.0	92.9	5.0	-4.5	37.1	-1.17%
1	1	2	a	> 10	0.0	62.0	9.5	0.0	54.7	-2.11%
11	1	2	a	5.0	2.3	115.0	4.0	4.3	104.6	-1.56%
21	1	2	a	2.5	0.5	103.7	3.0	-0.1	75.3	-0.48%
4	2	3	b	4.0	7.8	43.6	6.0	6.6	34.4	-2.05%
14	2	3	b	2.0	-3.5	33.2	2.0	-4.6	23.9	-3.31%
24	2	3	b	2.5	-0.2	43.8	2.0	0.8	39.7	-3.79%
6	2	3	a	5.5	-1.0	41.1	3.5	-6.0	36.5	-2.48%
16	2	3	a	3.0	3.1	44.1	2.0	1.4	47.6	-2.54%
26	2	3	a	1.5	2.1	38.9	0.0	2.4	43.8	-2.43%
2	2	2	b	2.0	-4.2	30.1	2.5	-0.6	29.1	-1.79%
12	2	2	b	4.5	0.3	26.9	3.0	5.0	33.2	-1.11%
22	2	2	b	4.5	0.4	72.7	2.5	-1.4	51.4	-1.73%
30	2	2	b	4.5	-1.6	41.0	2.5	-1.8	63.0	-2.14%
4	2	2	a	4.5	-7.6	36.3	6.0	-10.8	27.2	-2.28%
14	2	2	a	2.0	-2.6	81	1.5	1.6	89.1	-1.91%

Table 6 – pointwise comparison of TMS, level point measurement, APL and crossfall

The columns with header "TMS" give the measured opening under the beam ("> 10" means that the opening was bigger than 10mm, bigger than what can be measured with precision by the TMS). The columns with the header "point level difference" give the relative difference between two consecutive point level measurements (for instance, in the first line of Table 6 the point level difference is the difference between point levels measured at position 8 and position 9). The values in the columns with header "EC2.5m (APL)" are the $EC_{2,5m}$ values obtained from the APL measurements on the block of E=10m length centered around the point with the position number as given in the first column. When comparing the values in these columns with the other ones, one must keep in mind that the identification of the point on which the $EC_{2,5m}$ block is centered is hazardous.

Also the data from the level point measurements were compared to the TMS data. Whereas the TMS results are not influenced by the cross fall when the beam is placed in longitudinal direction, a direct relationship can be observed with height variations in the longitudinal direction. A peak in the height level effects several consecutive point measurements with the TMS. High values obtained from the TMS can immediately be retraced to a local variation in height level.

Two phenomena were observed from the comparisons of all the available data. Firstly, a comparison between APL data and level point measurements show that the APL is not a topographic device: the APL data are not influenced by long wavelenghts. This is illustrated in Figure 5: the APL registers an almost horizontal profile whereas the real profile is decending continuously. (In order to compare the data on the same graph, a shift by an offset value was applied to one of the curves in Figures 5, 6 and 7, and the distance on the X-axis was set arbitrarily to 0 at the beginning of the sub-section.)

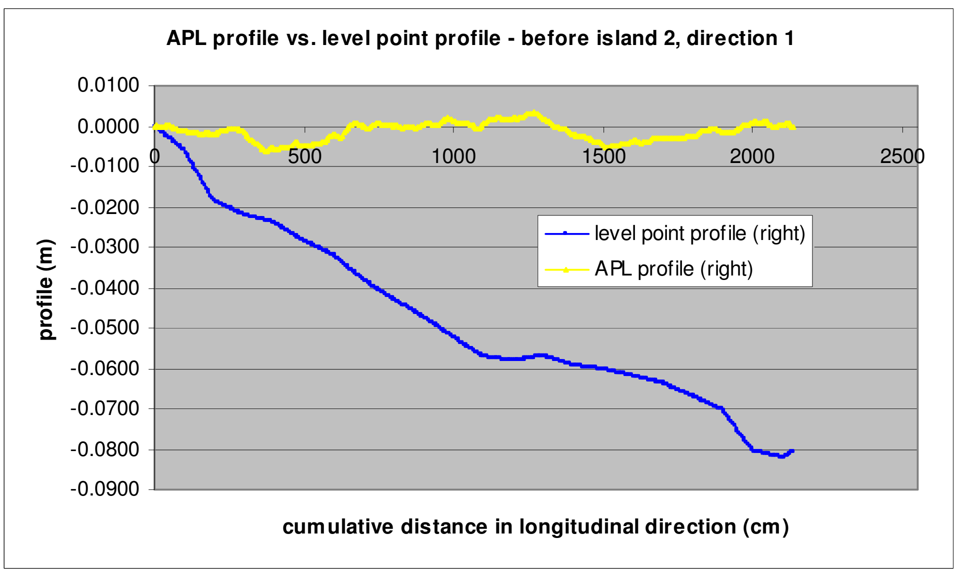

Figure 5 – APL is not a level point measurement device

Secondly, at one of the eight sub-sections a kink in the APL profile is observed although the level point measurements do not show such a kink in the real road profile. However, as illustrated in Figure 6, the real road profile does change rather dramatically on a very short distance. This phenomenon in the APL data may very well be explained by an influence of the towing car on the APL trailer. The variation of the crossfall at this location is shown in Figure 1. When computing the EC_B, the APL trailer data produce a local overestimate for B=2,5m on a block of E=10m. The EC_{10m} on a block of E=25m or more will not be influenced significantly.

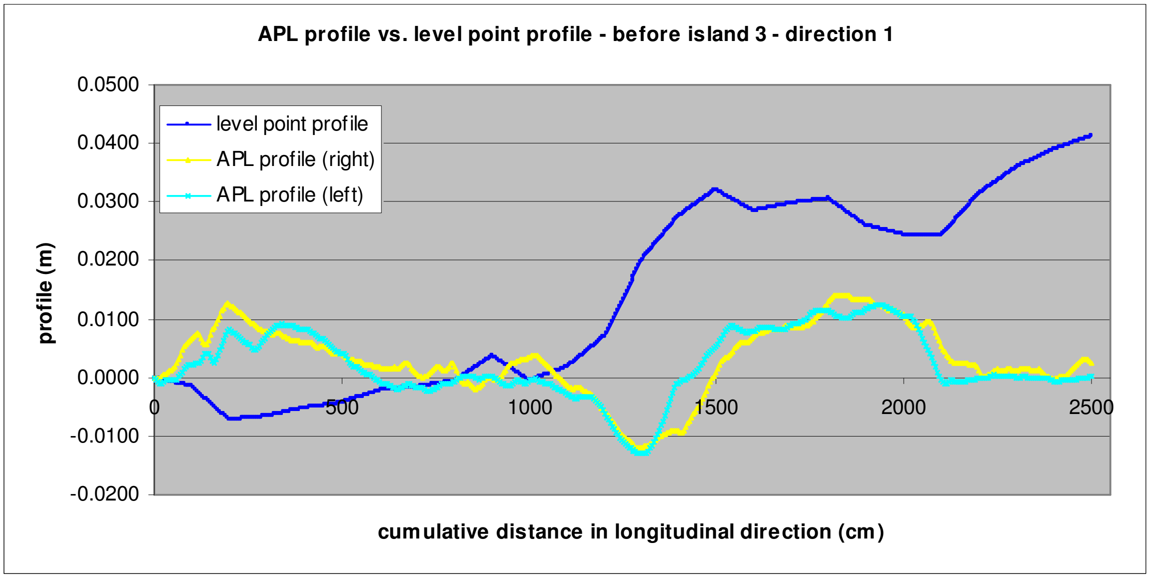

Figure 6 – exceptional phenomenon in APL profile – influence of towing car?

Since the APL measurements where repeated 3 times at constant speed 21,6km/h and 3 times at constant speed 54km/h, 6 profiles were available. All show a bump as in Figure 6.

A similar situation seems to have occurred at the end of another sub-section. As illustrated in Figure 7, the APL in the wheelpath on the right side does not identify an important change in the road profile that was detected by the level point measurements. The level point measurements also reveal that the change in the road profile in the wheelpath on the left of the lane is a bit smoother (see Figure 7) and that the variation of the crossfall is not very wavy (see Figure 8). When comparing the measurements obtained with the two APL trailers in the different wheelpaths they appear to be very similar. We therefore think that on this particular location the APL was not influenced by the towing car and the crossfall and that the change in longitudinal evenness is not as important as to give rise to high values for the $EC_{2,5m}$. In this case the APL somewhat underestimated the unevenness of the road, bearing in mind that the APL is not a topographic device (cf. Figure 5).

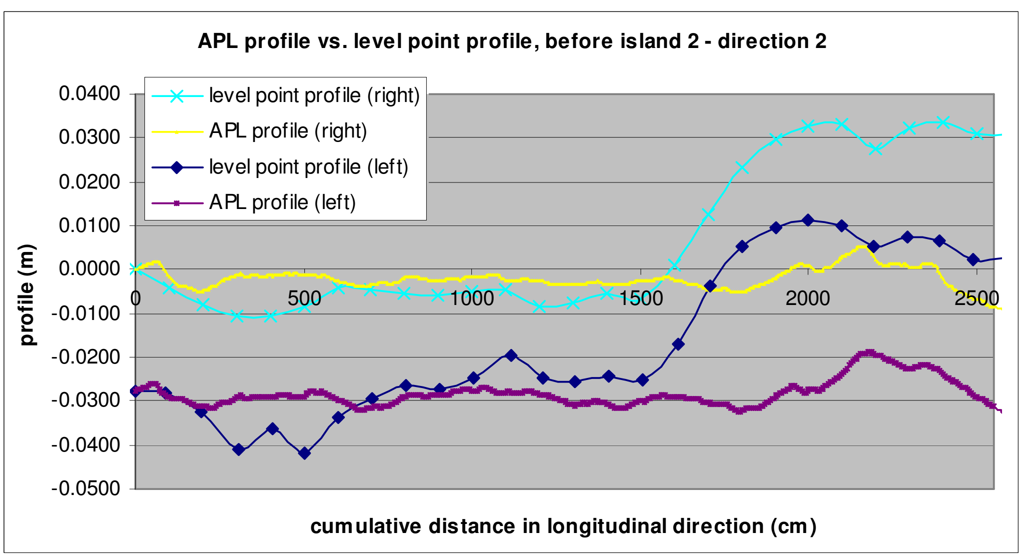

Figure 7 – the APL profile missed an abrupt change in evenness

When comparing all 6 APL profiles with each other, again they all look very similar.

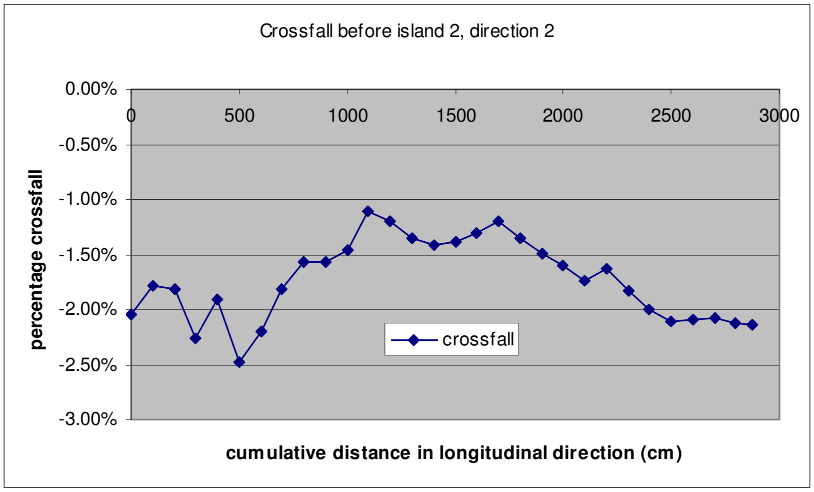

Figure 8 – change of crossfall “between 1500cm and 2000cm” is not very wavy

5. WIDER PERSPECTIVES OF THE CASE STUDY RESULTS

From the theoretical analysis and from the experiments in the case study presented, it can be concluded that the APL and the evenness coefficient does give an accurate indication of the quality of the evenness of a newly constructed road section. The case study revealed that the towing car may influence the APL measurements but it also showed that this occurs when the road surface presents an important unevenness on a very short distance and that it will only have a very local effect on the reported results. This observation cannot be used as an argument refuting the APL or the evenness coefficient since the phenomenon is indeed the consequence of an existing unevenness of the road surface. The case study also indicates that the APL measurements can be influenced by cross fall when the cross fall changes in a non monotonous way. Again, the results from APL measurements are then slightly influenced by an existing unevenness, be it a transverse one. The case study rather comforts the idea that the APL measurements are a reliable means for the verification of evenness after road works, which can be executed rapidly, after opening of the road to traffic and without major hindrance to traffic. The theoretical estimate of the height of unevenness under a “B-metre straightedge” is proven to be realistic in the examined case. This estimate can contribute to the choice of possible means of repairs: it can help making the analysis whether local interventions suffice for corrections to the evenness or whether the road surface layer must be replaced entirely over a longer distance.

The insight in the measurement techniques and the limits of the interpretation of the measurement results obtained with different tools and methods as presented above form the backbone of what is needed for normative actions and hence are indeed a first contribution to the above mentioned pre-normative project. Further investigations of different indicators are foreseen in 2012.

6. CONCLUSIONS

This contribution discussed the finesses of longitudinal evenness measurements expressed with the indicator EC_B obtained by APL measurements. It presented results of a case study where the EC_B obtained by APL were compared to TMS and level point measurements on eight sub-sections where unevenness was clearly present. In the case study, the theoretical estimate of the gap height under a “B-metre straightedge” was proven to be consistent with TMS measurements. Non monotone crossfall and very important isolated longitudinal variation in evenness may influence APL measurements locally. However, in those cases an important unevenness is clearly present. The case study rather comforts the perception that APL measurements are a reliable means for the verification of evenness after road works. The gap height estimate from APL data can contribute to the global evaluation of the appropriate intervention for maintenance or repairs.

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