Close Proximity (CPX) Round Robin Test 2017

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Introduction

Reduction of traffic noise is of great benefit to society. Therefore, silent tyres and silent pavements have been developed and are continuously improved. To measure the performance of silent pavements, measurements of tyre/road noise generated on different pavements are necessary. The Close Proximity (CPX) method, standardized in ISO 11819-2 [1], is widely used as measurement method for tyre/road noise.

In spring 2017 a Close Proximity Round Robin Test (RRT) was conducted in the Netherlands. In total 9 CPX-systems participated in this test. This included CPX-systems from Austria, Belgium, Germany and the Netherlands.

In this paper the results of the CPX-RRT are presented. The goal of the RRT was to look at the consistency of the measurement results in practice, and to see if the differences between CPX-levels measured by different parties and measurement systems are within acceptable margins. Measurements and analysis have been performed according to the Dutch "CROW Protocol for admission and round robin test of CPX devices" [2]. This paper explains the RRT protocol and the results, including repeatability and reproducibility. In addition, attention will be paid to the effect of applying a correction for the influence of rubber hardness on the CPX-levels.

Round Robin Test / CPX protocol

The CPX round robin test organised by the Dutch CROW in cooperation with the Dutch National Road Authority, aims to improve the repeatability and reproducibility of CPX measurements for the Dutch market, by rejecting CPX devices which do not meet the requirements of the protocol.

The CPX-results are assessed based on trueness and precision. Trueness refers to the closeness of agreement between the arithmetic mean of test results and the true or accepted reference value. Precision refers to the closeness of agreement between test results. Within precision two conditions are defined: repeatability and reproducibility.

Repeatability and reproducibility are used in the CPX-RRT only to assess the compliance of the CPX devices according to the protocol. The CPX-RRT does not aim to determine the repeatability and reproducibility of the CPX ISO-standard in general.

Trueness cannot be assessed absolutely, as the quantity to be measured is not of a permanent sample but of an interaction phenomenon between tyre and road pavement, both of which may vary with time and location. Therefore trueness will be assessed relative to a reference consisting of the average of the results of all participants, except where these have been excluded from the reference average because of excessive discrepancy from the other devices.

Admission

To be admitted for the CPX-RRT each applicant CPX device has to be certificated and calibrated according to the requirements of ISO/DIS 11819-2 [3], within 24 months previously to the RRT. All instrumentation shall comply with the requirements specified in ISO/DIS 11819-2.

In limitation of the options in ISO/DIS 11819-2, a Dutch requirement is that measurement trailers shall be constructed as two-wheeled trailers. The test wheels shall roll in the left and right wheel tracks of the traffic lane. The axle track of the test wheels shall correspond as close as possible to the distance between the wheel tracks on the lane and shall measure 1,90 ± 0,10 m between the centre lines.

The CPX devices may be designed according to two enclosure options:

- trailer with enclosure lined with sound absorbing material,
- open trailer without enclosure.

For devices of both options the frequency-dependent device correction term *Cdf* shall be determined in accordance with the method described in ISO/DIS 11819-2. In addition, the instruments used for the measurement of the driving speed shall have a maximum permissible error of ± 1% of the indicated value.

The CPX-RRT measurements will only be performed with the Standard Reference Test Tyre (SRTT) according to the specifications of ASTM F2493-14 [4]. The Shore hardness of these test tyres (no more than 3 months old values), according to ISO/TS 11819-3 [5] shall be reported in advance, together with the calibration information (no more than 24 months old) of the Shore hardness tester used.

Figure 1: Overview of CPX-measurement systems that participated in the round robin test 2017.

Analysis of compliance with requirements

The analysis of the CPX measurement results is slightly different from the formal ISO-procedure. The analysis of compliance is done on A-weighted overall sound pressure levels SPL in dB(A) per 100 m section. The SPL values are analysed per individual measuring run, and not averaged over two runs. Measurement results are not corrected for the rubber hardness of the tyres in the compliance assessment, but the effect of hardness variations is investigated separately.

Test sections

According to the CPX-RRT protocol [2] the measurements should be performed on an open and dense road surface with at least 1000 m length. Both road surface types should have a good acoustic homogeneity (standard deviation not more than 0,5 dB(A)). The reference speed for the measurements is 80 km/h and at least four measurement runs on both road sections should be performed.

For the CPX-RRT 2017 a double layered porous asphalt concrete (DLPAC) and SMA-NL 11B were selected.

Figure 2: Preparation CPX-measurement systems for the round robin test 2017.

Analysis of trueness

The analysis of trueness is performed separately on each tested road section, or combination of subsections per pavement type in case of sections of less than 1000 m contiguous length.

First the reference value of each 100 m section of each road section is determined in the following steps:

- Collect the sound pressure levels (SPL) for all participants for all runs for all 100 m sections,
- Determine per participant, for each 100 m section, the average and standard deviation of the SPL over all runs,
- Indicate the whole group of all participants as the reference group,
- Determine per 100 m section the overall average of the SPL over all runs of the reference group. These are called the reference values per 100 m section,
- Determine per participant per 100 m section the absolute value of the difference between the participant's average and the reference value,
- If the reference group consists of more than three participants, check whether the differences from the previous step are less than 1,0 dB(A) for each 100 m section. If not, the participant with the largest difference is excluded from the reference for that 100 m section, and the previous two steps are repeated.

The result of these steps is a final reference value per 100 m section. Then it will be determined if each participant fulfils the trueness requirements, in the following steps:

- Determine per participant, per 100 m section and per run the difference between the participant's SPL value and the reference value,
- Determine per participant, for each 100 m section, the average and standard deviation of the SPL differences of the previous step over all runs,
- Determine per participant, the average of the SPL differences of the first step over all 100 m sections. This value is called 'A',
- Determine per participant, the standard deviation of the SPL differences of the first step over all 100 m sections. This is called 'B',
- The absolute value of 'A' shall be less than 1,0 dB(A),
- The value of 'B' shall be less than 1,3 dB(A),
- A participant fulfils the trueness requirements, if both requirements for 'A' and 'B' are fulfilled.

Real "trueness" cannot be determined for CPX measurements, as the "true" value is unknown. Therefore, the group average (excluding outliers) is taken as the "accepted" reference value. The average deviations of a device ('A') from the group average constitute the bias (systematic error) of that individual device: a large bias indicates that the individual device measures generally higher, or generally lower, values than the rest. The random error value ('B') represents the ability of the individual device to accurately reproduce the variations of the road surface within the measurement section.

Analysis of precision

The analysis of precision is performed separately on each tested road section, or combination of subsections per pavement type in case of sections of less than 1000 m contiguous length, according to the following steps:

- Determine per participant for each 100 m section, the standard deviation of the SPL values over all runs,
- Determine per participant the root mean square of the SPL standard deviations of the previous step over all 100 m sections. This is called 'C',
- The value of 'C' shall be less than 0,5 dB(A),
- A participant fulfils the precision requirements if the requirement for 'C' is fulfilled.

Table 1: Overview requirements of protocol for parameters 'A' (systematic error), 'B' (indication of random error) and 'C' (indication of repeatability).

A [dB]	B [dB]	C [dB]
< 1,0	< 1,3	< 0,5

To explain the parameters 'A', 'B' and 'C' in more detail a fictive example of measurements over a length of 500 m is shown in figure 1. The black line represents the group average per 100 m section. The other lines indicate the results of three measurement runs performed by one measurement device 'Z'. Other measurement devices are not shown. In this example device 'Z' has a small average difference with respect to the reference (small 'A'), but a relatively large variation in differences with respect to the reference (large 'B'). The variation is not caused by accidental variations between repeated measurement runs, because this variation is smaller (small 'C').

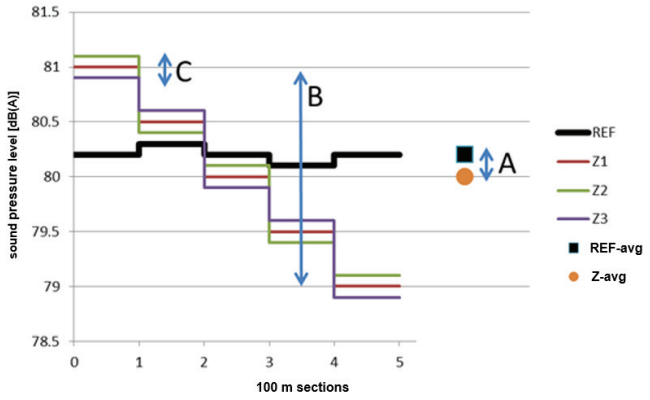

Figure 3: Explanation of the parameters 'A', 'B' and 'C in the CPX protocol RRT.

Results

In total 9 CPX-systems joined the CPX-RRT in May 2017. Eight CPX-trailers had an enclosure and one had no enclosure. All CPX-systems fulfilled the admission requirements according to the CPX-protocol. Instead of the prescribed four measurement runs on each road section all participants performed in total six measurement runs.

The CPX-RRT protocol is based on ISO/DIS 11819-2. This means that there will be no tyre rubber hardness correction, since this correction was only introduced in the successive ISO-standard. The effect of rubber hardness was investigated separately (see below). The CPX-systems were numbered from CPX01 till CPX09 in random order.

The first step in the analysis process is the determination of the reference value (group average) of each 100 m road section. This resulted in the exclusion of the following data:

- CPX01 on SMA (12 of 12 segments excluded),
- CPX01 on DLPAC (4 of 9 segments excluded),
- CPX02 on DLPAC (9 of 9 segments excluded),
- CPX03 on DLPAC (1 of 9 segments excluded).

The results of determination of the parameters 'A', 'B' and 'C' are shown in table 2. To be able to see the differences between the CPX-systems in more detail the value of parameter 'A' is not presented as an absolute value, according to the protocol, but as a +/- value.

Table 2: Evaluation of CPX-results per participant. The 'A' value (absolute value) determines the average of the SPL-differences per 100 m section (systematic error), 'B' is the standard error of the differences for all 100 m sections (indication of random error) and 'C' is the RMS of the differences for all 100 m sections (indication of repeatability)Values for parameter 'A' are not presented as an absolute value.

participant	SMA-NL 11B		
	A [dB]	B [dB]	C [dB]
CPX01	**1,37**	0,13	0,12
CPX02	-0,30	0,11	0,11
CPX03	0,87	0,21	0,15
CPX04	-0,61	0,25	0,21
CPX05	0,48	0,14	0,12
CPX06	0,09	0,12	0,12
CPX07	0,07	0,20	0,21
CPX08	-0,33	0,22	0,22
CPX09	-0,27	0,11	0,09
min.	*-0,61*	*0,11*	*0,09*
max.	*1,37*	*0,25*	*0,22*
range	*1,98*	*0,14*	*0,12*
stdev.	*0,64*	-	-
participant	DLPAC		
	A [dB]	B [dB]	C [dB]
CPX01	0,91	0,17	0,09
CPX02	**-1,29**	0,12	0,08
CPX03	0,85	0,17	0,10
CPX04	-0,50	0,27	0,22
CPX05	-0,05	0,14	0,07
CPX06	0,40	0,15	0,09
CPX07	-0,79	0,16	0,14
CPX08	-0,39	0,12	0,11
CPX09	0,18	0,11	0,10
min.	*-1,29*	*0,11*	*0,07*
max.	*0,91*	*0,27*	*0,22*
range	*2,20*	*0,16*	*0,15*
stdev.	*0,74*	-	-

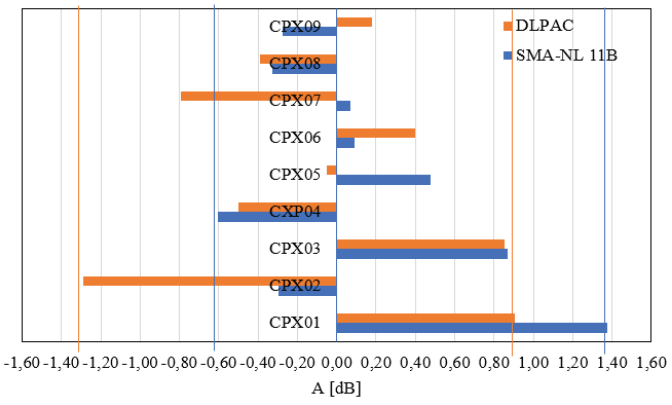

Figure 4: Overview of parameter 'A' values as none absolute value.

The bold values in table 2 do not meet the requirements of the protocol. This concerns the CPX-systems CPX01 and CPX02. The results in table 2 show a range (min-max) on SMA of 1.98 dB and on DLPAC of 2,20 dB with respectively a standard deviation of 0,64 dB and 0,74 dB.

Comparison CPX-RRT 2011

The previous CPX Round Robin Test in the Netherlands was conducted in 2011, also under the auspices of CROW [6]. In total 5 of the current 9 CPX-systems took also part in the 2011 CPX-RRT.

To compare the results (SRTT at 80 km/h) of 2011 with the results of 2017 the same approach as in 2011 was followed using data from the current CPX-RRT. The 2011 data consist of different road surfaces such as DAC, SMA, PAC and DLPAC.

In figure 5 the average differences per participant are given for both road sections in the CPX-RRT 2017 as well as for the CPX-RRT 2011. Remarkable are the small differences between the 2011 and 2017 results for most CPX-systems when averaging the results of both road surface types in 2017. This is shown in table 3.

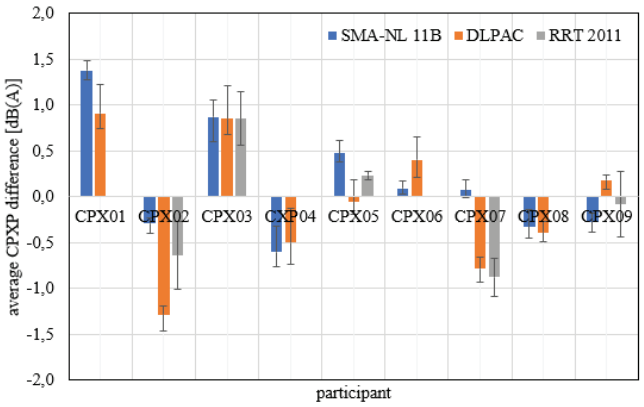

Figure 5: Average differences per participant on SMA and DLPAC, compared to the differences (mixture of road surface types) found in the CPX-RRT 2011. The error bars indicate min-max values.

Table 3: Average differences of participants which participated in the CPX-RRT 2011 as well as 2017

participant	average differences [dB]	
	RRT 2011	RRT 2017
CPX02	-0,64	-0,80
CPX03	0,85	0,86
CPX05	0,23	0,22
CPX07	-0,88	-0,36
CPX09	-0,08	-0,05

Correction tyre rubber hardness

In the current CPX-RRT protocol there is no correction for tyre rubber hardness. To illustrate the effect of tyre rubber hardness correction according to ISO 11819-2 and ISO/TS 11819-3 the analysis process was performed again based on the hardness corrected SPL. The tyre rubber hardness values were provided by the participants themselves. The reference rubber hardness value is 66 Shore A and the correction coefficient is 0,20 dB per Shore A.

The results of determination of parameter 'A' are shown in figure 6. The influence of applying a tyre rubber hardness correction is significant when comparing figure 6 and figure 4. Participants CPX01 and CPX02 did not meet the requirements without the hardness correction, but they do comply if the correction is applied. Participants CPX04 and CPX07 did comply without hardness correction, but do not comply if the correction is applied. All participants still fulfilled the requirements of parameter 'B' and 'C'.

The results show an improvement of the range (max-min) of parameter 'A' when the rubber hardness correction is applied. Without the correction, the range was 1,98 dB on SMA and 2,20 dB on DLPAC. After applying the correction, the range is 1,60 dB on SMA and 1,99 dB on DLPAC. The respective standard deviations of 0,49 dB and 0,68 dB are also smaller.

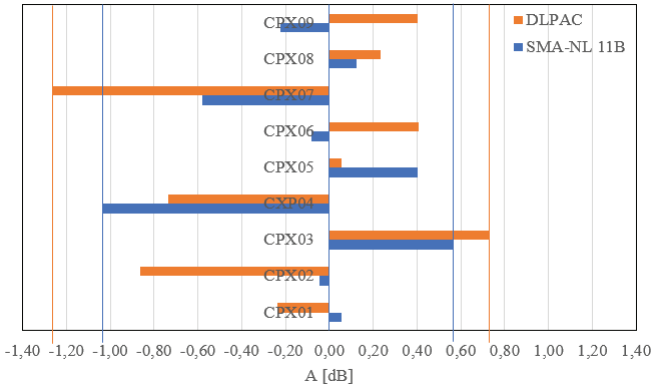

Figure 6: Overview of parameter 'A' values (none absolute value) when applying tyre rubber hardness correction.

Conclusions

The CPX Round Robin Test according to the CROW protocol went well. All participants were able to perform the measurements simultaneously within the given time frame.

The analysis of compliance showed that all participants fulfilled the requirements regarding random error ('B' parameter) and regarding repeatability ('C' parameter). Two participants did not meet the requirement regarding systematic errors ('A' parameter).

For the next CPX-RRT planned in 2019, it is recommended to update the protocol according to the latest ISO 11819-2 and ISO/TS 11819-3 so tyre rubber hardness correction is taken into account.

References

[1] ISO 11819-2, Part 2: The Close-Proximity method, 03-2017

[2] CROW protocol for admission and round robin test of CPX devices, 04-2016 https://www.crow.nl/thema-s/wegbeheer-en-wegonderhoud/inspecties-en-metingen/geluidsmetingen

[3] ISO/DIS 11819-2, Part 2: The Close-Proximity method, 12-2012

[4] ASTM 2493-14, Standard Specification for P225/60R16 97S Radial Standard Reference Test Tire, 2014

[5] ISO/TS 11819-3, Part 3:Reference tyres, 03-2017

[6] CROW report, CPX trailer comparison round robin test data analysis, 05-2012