Certain aspects of the CEN standard for the evaluation of ride comfort for rail passengers

B. Kufver[1], R. Persson[2] & J. Wingren[2]
[1]*Ferroplan, Sweden*
[2]*Bombardier Transportation, Sweden*

Abstract

The work of the European Committee for Standardization (CEN), Working Group CEN/TC256/WG7, concerns ride comfort for passengers. A European prestandard from 1999 for the measurement and evaluation of ride comfort for rail passengers has been revised by the working group. A draft standard prEN 12299 (Railway applications – Ride comfort for passengers – Measurement and evaluation) was sent for enquiry during 2006. From the CEN members, the national standardisation bodies of 28 countries, more than 300 technical and editorial comments were received. WG7 then produced a revised draft standard, which in 2009 was accepted as a European standard. The present conference paper discusses certain parts of EN 12299:2009, with a focus on data processing, the application of computer methods and interpretation of results.
Keywords: ride comfort for passengers, CEN, European standards, EN 12299.

1 Introduction

The European Committee for Standardization (CEN) has a Technical Committee TC256, defining European standards for the railway sector.

In 1999, a European prestandard for measurements and evaluation of ride comfort for rail passengers ENV 12299 [1] was published. The prestandard defines methods for quantifying the effects of vehicle body motions on ride comfort for passengers. These methods have originally been developed by Office for Research and Experiments of the International Union of Railways (ORE) (N_{MV}, N_{VA} and N_{VD} methods) [2] and British Rail Research (BRR) (P_{CT} and P_{DE} methods) [3].

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Recently, the prestandard ENV 12299 has been revised by Working Group CEN/TC256/WG7. Active experts in WG7 have been nominated from the national standardisation bodies of France, Germany, Italy, and Sweden, and come from the companies Alstom, Bombardier, Deutsche Bahn (DB), Ferroplan, Siemens, La Société Nationale des Chemins de Fer Français (SNCF), Trenitalia and the Swedish National Road and Transport Research Institute (VTI). An enquiry version of the new standard was submitted to CEN during 2006 and more than 300 technical and editorial comments were received and taken into account for the final version of the new standard EN 12299 [4] which was approved and published in 2009. The aim of the present conference paper is to present certain parts of the new standard, with a focus on data processing, application of computer methods and interpretation of results.

2 Basic principles in the comfort standard EN 12299

Comfort is measured in an indirect way. Motions of a vehicle are mostly measured by accelerometers and gyros fitted to the vehicle body at certain positions. Direct tests based on test subjects are not defined in EN 12299 [4], even though certain guidelines are given in an informative annex. The Mean Comfort Complete Method N_{VA} (described in Clause 5 of this paper) makes use also of accelerometers in the interface between the seat pan/seat back and the passenger.

Vehicle conditions, accelerometer positions, test speed, selection of test sections, relevant time intervals etc. are defined for each method.

The accelerometer and gyro signals shall be band-pass or low-pass filtered. The weighting curves W_c and W_d for lateral and longitudinal motions are the same as in ISO 2631-1 [5], while the low-pass filter W_p (used in the P_{CT} and P_{DE} methods) and the weighting curve W_b for vertical direction are special filters for railway applications.

Post-processing of the filtered signals, such as sliding window calculations, rms calculations, averaging procedures and statistical analysis is defined for each method.

The scope of the standard is to define relevant methods for the evaluation of ride comfort. In an annex, the procedures for vehicle assessment with respect to one of the comfort methods are defined.

3 The mean comfort standard method N_{MV}

The Mean Comfort Standard Method quantifies comfort during a continuous five-minute run for a seated passenger. Weighting curves W_b and W_d are used, extracting vibrations in the frequency range 0.4 Hz – 100 Hz. Hence, the method neglects quasi-static acceleration due to curving. The method is validated for fairly straight lines.

The accelerations are measured in the longitudinal (x), lateral (y) and vertical (z) directions. After frequency weighting, sixty continuous (and not overlapping) five-second weighted rms accelerations are calculated for each direction. From the sixty rms values, the 95th percentile (i.e. the 4th highest value) is used for further processing.

Finally, the 95th percentiles of the weighted accelerations in the three directions ($a_{XP95}^{W_d}$ etc) are combined with an rss (root-sum-square) calculation according to eqn (1), valid for a 5-minute period.

$$N_{MV} = 6 \cdot \sqrt{(a_{XP95}^{W_d})^2 + (a_{YP95}^{W_d})^2 + (a_{ZP95}^{W_b})^2} \tag{1}$$

The resulting N_{MV} value may be interpreted according to Table 1. Based on experiences from France, Germany and Sweden, the scale is slightly modified compared with the corresponding scale in the prestandard ENV 12299 [1].

The N_{MV} method has many similarities with traditional vibration analysis according to ISO 2631-1 [5]. The controversial point is the use of 95th percentiles where only the 4th highest value is considered. The consequences are that the three hypothetical 5-minute vibration patterns in Table 2 are considered equally comfortable, which seems doubtful.

Another problem is that it is not possible to connect the resulting N_{MV} value to a certain location along the track and the local track irregularities, since the three 95th percentiles of the x, y and z accelerations may occur during three different five-second time intervals (and consequently at three different locations).

4 Continuous comfort C_{Cx}, C_{Cy} and C_{Cz}

Since the N_{MV} method makes use of the 95th percentiles only, there is a substantial loss of information. Therefore, CEN/TC256/WG7 proposes that all five-second rms values are reported from comfort tests. This will enable further analysis and comparisons between different vibration measurements. These five-second rms values define a times series for x, y and z directions, respectively (called Continuous Comfort $C_{Cx}(t)$, $C_{Cy}(t)$ and $C_{Cz}(t)$).

Table 1: Scale for the N_{MV} comfort index in EN 12299 [4].

$N_{MV} < 1.5$	Very comfortable
$1.5 \leq N_{MV} < 2.5$	Comfortable
$2.5 \leq N_{MV} < 3.5$	Medium
$3.5 \leq N_{MV} < 4.5$	Uncomfortable
$N_{MV} \geq 4.5$	Very uncomfortable

Table 2: Three hypothetical five-minute vibration patterns for one direction (each of sixty five-second rms values, m/s^2).

	First highest rms value	2nd	3rd	4th	5th	ith	60th
Series A	0.3	0.3	0.3	0.3	0.1	0.1	0.1
Series B	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Series C	0.9	0.9	0.9	0.3	0.3	0.3	0.3

Table 3: Preliminary scale for the $C_{Cy}(t)$ and $C_{Cz}(t)$ comfort indexes.

$C_{Cy}(t)$, $C_{Cz}(t) < 0.20$ m/s^2	Very comfortable
0.20 m/s$^2 \leq C_{Cy}(t)$, $C_{Cz}(t) < 0.30$ m/s^2	Comfortable
0.30 m/s$^2 \leq C_{Cy}(t)$, $C_{Cz}(t) < 0.40$ m/s^2	Medium
$C_{Cy}(t)$, $C_{Cz}(t) \geq 0.40$ m/s^2	Less comfortable

A preliminary scale for assessments of individual $C_{Cy}(t)$ and $C_{Cz}(t)$ values is given in EN 12299, Table 3.

5 Mean comfort complete methods N_{VA} and N_{VD}

The Mean Comfort Complete Methods (N_{VA} and N_{VD}) quantify comfort during a continuous five-minute run, in analogy with the Mean Comfort Standard Method (N_{MV}). The N_{VA} method is based on accelerometer measurements not only at the floor (vertical direction), but also in the interfaces between a seated passenger and the seat pan (lateral and vertical directions) and seat back (longitudinal direction). This makes the method substantially more cumbersome to use, both in real comfort tests and in computer experiments. The N_{VA} comfort index is based on 95th percentiles of the measured accelerations.

The N_{VD} method is validated for standing passengers. Accelerations are measured at the floor only. The N_{VD} comfort index is based on median values of the measured accelerations in all three directions and on the 95th percentile of the measured accelerations in the lateral direction. The ORE B153 expert committee achieved the best correlation between comfort ratings and vehicle motions when the maximum values and not the 95th percentiles were used [2]. However, it was believed the method would be too sensitive to anomalies if it was based on the exceptional values. Whether the method is based on maximum values or 95th percentiles does not really affect the sensitivity to outliers, and does not eliminate the fact that Series A and Series B in Table 2 would be rated equal with the N_{VD} value.

Both Mean Comfort Complete Methods have the same substantial loss of information in the statistical analysis as the Mean Comfort Standard Method: Most five-second rms values have no influence at all in the final calculation. In addition, both methods have the characteristic that it is not possible to connect the resulting N_{VA} or N_{VD} value to a certain location along the track since the relevant 95th percentiles (and median values) may occur during different five-second time intervals.

6 Comfort on discrete events P_{DE}

Comfort on discrete events, P_{DE}, is based on research at British Rail Research (BRR) [3]. The tilting APT and non-tilting HST were used for test runs, where test subjects were instructed to press a button if any aspects of the lateral ride were considered "Uncomfortable" or "Very uncomfortable" on a scale "Very comfortable” – “Comfortable” – “Acceptable” – “Uncomfortable” – “Very uncomfortable”.

BRR found that comfort disturbances were reported at large track irregularities or transition curves. These two cases were analysed separately. For large track irregularities, it was found that the percentage of passengers indicating discomfort depends on two variables: Mean lateral acceleration (due to curvature and cant) and peak-to-peak lateral acceleration.

The P_{DE} method was slightly modified in ENV 12299 [1], with the aim of less manual application. A 2 Hz low-pass filter W_P was introduced and a procedure using a two-second sliding window was defined. Within this window, peak-to-peak lateral acceleration $\ddot{y}_{\mathrm{pp}}(t)$ and mean lateral acceleration $|\ddot{y}_{\mathrm{2s}}(t)|$ shall be calculated according to eqns (2) and (3).

$$\ddot{y}_{\mathrm{pp}}(t) = \max\left(\ddot{y}^*_{\mathrm{P,Wp}}(\tau), \tau \in \left]t-\frac{T}{2}, t+\frac{T}{2}\right]\right), \\ -\min\left(\ddot{y}^*_{\mathrm{P,Wp}}(\tau), \tau \in \left]t-\frac{T}{2}, t+\frac{T}{2}\right]\right) \tag{2}$$

$$|\ddot{y}_{\mathrm{2s}}(t)| = \frac{1}{T}\left|\int_{t-\frac{T}{2}}^{t+\frac{T}{2}} \ddot{y}^*_{\mathrm{P,Wp}}(\tau)d\tau\right| \tag{3}$$

where T=2 seconds and $\ddot{y}^*_{\mathrm{P,Wp}}(\tau)$ is the low-pass filtered lateral acceleration of the vehicle body.

From these running peak-to-peak and mean lateral accelerations, running $P_{DE}(t)$ for standing and seated passengers can be defined, eqns (4) and (5), respectively. The P_{DE} functions represent the percentage of the passengers rating the ride as uncomfortable or very uncomfortable. It may be noted that the P_{DE} functions may take values above 100, but such high values are outside the interesting range of application.

$$P_{\mathrm{DE}}(t) = \max\left[16.62 \cdot \ddot{y}_{\mathrm{pp}}(t) + 27.01 \cdot |\ddot{y}_{\mathrm{2s}}(t)| - 37.0;0\right] \tag{4}$$

$$P_{\mathrm{DE}}(t) = \max\left[8.46 \cdot \ddot{y}_{\mathrm{pp}}(t) + 13.05 \cdot |\ddot{y}_{\mathrm{2s}}(t)| - 21.7;0\right] \tag{5}$$

The comfort index $P_{DE}(t)$ is a continuous signal as a function of time and can be reported as such. For the assessment of a particular local event (which will affect the two-second sliding window during about 4 seconds), the local maximum of $P_{DE}(t)$ shall be used.

Examples of the shape of the $P_{DE}(t)$ function are given in Figure 1. Note that even though the discrete events generate distinct peaks of the low-pass filtered lateral acceleration $\ddot{y}_{\mathrm{P,Wp}}(t)$, the shape of the $P_{DE}(t)$ function may be less transient.

Originally, the P_{DE} functions were derived and validated for circular curves and straight track only. Comfort disturbances on a transition curve, or within

3 seconds, from a transition curve were neglected [3]. When eqns (4) and (5) are applied on acceleration data measured on a transition curve, which ENV 12299 [1] and EN 12299 [4] allow, both a mean value of lateral acceleration $|\ddot{y}_{2s}(t)|$ and a lateral peak-to-peak acceleration value $\ddot{y}_{pp}(t)$ will be quantified within the two-second sliding window. This can be seen for the transition curves in the time intervals $2s \le t \le 4s$ and $11s \le t \le 13s$ in Figure 1.

For a short transition curve with a high lateral jerk, the mean value of lateral acceleration $|\ddot{y}_{2s}(t)|$ and the lateral peak-to-peak acceleration value $\ddot{y}_{pp}(t)$ may be high enough to generate $P_{DE}(t)$ values above zero. See Figure 2 for a 2-second

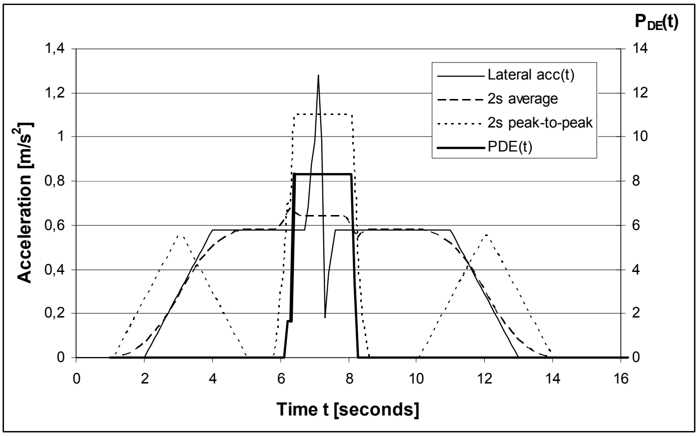

Figure 1: Examples of low-pass filtered lateral acceleration $\ddot{y}_{P,Wp}(t)$ and $P_{DE}(t)$ functions. The 2-second average $\ddot{y}_{pp}(t)$ and 2-second average $\ddot{y}_{2s}(t)$ functions are also illustrated.

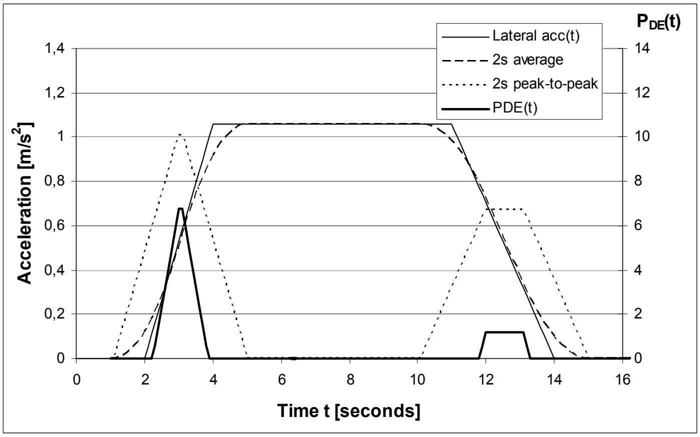

Figure 2: Example of the response from the $P_{DE}(t)$ evaluation on transition curves with high lateral acceleration and high lateral jerk. In these cases, P_{CT} should be evaluated instead of P_{DE}.

and a 3-second transition with high lateral jerk. In such cases, the corresponding P_{CT} value (defined below) will be higher and should be considered the best quantification of the comfort disturbance, at least when the transition leads to a higher lateral acceleration.

7 Comfort on curve transitions P_{CT}

The P_{CT} comfort index was derived from the same test runs as the P_{DE} comfort index. It was found that passenger discomfort occurred on entry transitions, reverse transitions and transitions with increasing lateral acceleration within compound curves. Transition curves with decreasing lateral acceleration did not generate discomfort [3]. It was also found that discomfort was related to maximum lateral acceleration, maximum lateral jerk and maximum roll velocity during the transition.

ENV 12299 [1] provided some further definitions for the P_{CT} method. Low-pass filter W_P was introduced and procedures using a one-second sliding window were defined. Within this window, lateral acceleration $\ddot{y}_{1s}(t)$ shall be averaged according to eqn (6). Roll velocity shall be averaged in the same manner, eqn (7), and lateral jerk shall be calculated according to eqn (8).

$$\ddot{y}_{1s}(t)=\frac{1}{T}\cdot\int_{t-\frac{T}{2}}^{t+\frac{T}{2}}\ddot{y}^{*}_{Wp}(\tau)d\tau \tag{6}$$

$$\dot{\varphi}_{1s}(t)=\frac{1}{T}\cdot\int_{t-\frac{T}{2}}^{t+\frac{T}{2}}\dot{\varphi}^{*}_{Wp}(\tau)d\tau \tag{7}$$

$$\dddot{y}_{1s}(t)=\frac{1}{T}\cdot\left(\ddot{y}_{1s}(t+\frac{T}{2})-\ddot{y}_{1s}(t-\frac{T}{2})\right) \tag{8}$$

where $T = 1$ second.

From each of these three time series, maximum absolute value should be selected within a certain time window before, during and/or after the passage of the transition curve. For lateral acceleration, the evaluation time starts at the beginning of the transition and ends 1.6 seconds after the end of the transition. Roll velocity should only be evaluated during the transition and lateral jerk should be evaluated from 1 second before the start of the transition to the end of the transition. These three time windows are difficult to handle in practice and require manual handling of the evaluation at the various transition curves. Also, the method for identification of the starting and ending points of the transition curves given in ENV 12299 [1] has been found inaccurate [7] and was deleted from EN 12299 [4].

The local maxima of the absolute values are used for calculation of P_{CT} for standing and seated passengers according to eqns (9) and (10), respectively.

$$P_{\mathrm{CT}} = \max\left[28.54 \cdot \left|\ddot{y}_{1\mathrm{s}}\right|_{\max} + 20.69 \cdot \left|\dddot{y}_{1\mathrm{s}}\right| - 11.1);\ 0\right], \\ + (27.36 \cdot \left|\dot{\varphi}_{1\mathrm{s}}\right|_{\max})^{2.283} \tag{9}$$

$$P_{\mathrm{CT}} = \max\left[(8.97 \cdot \left|\ddot{y}_{1\mathrm{s}}\right|_{\max} + 9.68 \cdot \left|\dddot{y}_{1\mathrm{s}}\right|_{\max} - 5.9);\ 0\right], \\ + (15.56 \cdot \left|\dot{\varphi}_{1\mathrm{s}}\right|_{\max})^{1.626} \tag{10}$$

Since the procedure with the three time windows is cumbersome in practice, Working Group CEN/TC256/WG7 made certain experiments with an automatic procedure with a running $P_{CT}(t)$. A possible function to replace the manual analysis with eqn (9) is given by eqn (11).

$$P_{\mathrm{CT}}(t) = \max\Big\{0; (28.54 \cdot \left|\ddot{y}_{1\mathrm{s}}(t)\right|, \\ +20.69 \cdot \max\left(\operatorname{sign}(\ddot{y}_{1\mathrm{s}}(t)) \cdot \dddot{y}_{1\mathrm{s}}(\tau), \tau \in \left]t - T_A - 2.6\mathrm{s}, t\right]\right)\Big\}, \\ +(27.36 \cdot \max\left(\left|\dot{\phi}_{1\mathrm{s}}(\tau)\right|, \tau \in \left]t - T_A - 1.6\mathrm{s}, t\right]\right))^{2.283} \tag{11}$$

The parameter T_A (seconds) should be chosen large enough to allow high lateral jerk and high roll velocity to affect the P_{CT} evaluation even if they occur in the beginning of a long transition curve, but small enough in order to exclude these values when they do not belong to the same transition as the lateral acceleration at the time t. Due to lack of experiences of the applications of an automatic procedure, it was not included in the standard EN 12299 [4].

8 Vehicle assessment with respect to ride comfort

The purpose of the standard EN 12299 [4] is primarily to define how to quantify ride comfort, independent of the cause(s) of any comfort disturbances (such as track irregularities, variations in track stiffness, vehicle design, maintenance status of the vehicle, interaction with adjacent vehicles, running speed, etc.). However, even though the Mean Comfort Standard Method is sensitive to more or less exceptional values (as discussed in Clause 3), it is often used for vehicle assessment with respect to ride comfort. In such application, some further specifications are necessary and modifications may be needed. These alterations are specified in an annex to the standard.

Assessing vehicles with respect to ride comfort implies that it must be possible for the vehicle contribution to the ride comfort to be separated from the total ride comfort. However, the acceleration levels are highly correlated to the track features and track quality, which means that a few local disturbances, such as passing a turnout or a level crossing, may result in a higher comfort index. Hence, selecting the test sections becomes a critical process ensuring that operating conditions are representative of the tested vehicle. Test sections shall also be selected in such a way that the track quality corresponds to the one specified for the running speed required. Keeping the speed constant during the test zones of five minutes is a third requirement on test sections. Finding test sections meeting all these requirements may be very challenging in some countries and the new standard EN 12299 [4] is therefore suggesting a few modifications to the Continuous Comfort in case of vehicle assessment:

a. The acceleration values may be calculated over track sections of certain length instead of five-second periods.
b. The samples may be taken from a non-continuous measurement and grouping data as proposed in the European standard EN 14363 [7].

These modifications, together with the acceptance to use the same accelerometer positions as proposed in EN 14363 [7], will simplify homologation of vehicles as the same test sections and the same accelerometers may be used for ride comfort as for running behaviour.

9 Discussion and conclusions

The new standard EN 12299 [4], as well as the previous prestandard ENV 12299 [1], defines methods for comfort evaluation which were originally developed by Office for Research and Experiments of the International Union of Railways (ORE) and British Rail Research (BRR). The methods are well established and have been used for many years.

However, there are still some missing links to an overall comfort evaluation which can be used to optimise ride comfort against for example travel time. While a lot of research has been conducted in order to make a monetary assessment of travel time, comparatively little has been conducted in the field of monetary assessment of ride comfort, even though there are some studies, such as [8]. There is also lack of knowledge in the field of motion sickness [9].

The N_{MV}, N_{VA} and N_{VD} methods are believed to be valid on fairly straight lines, but have certain dubious characteristics, such as neglecting 98.3% of the measured rms vibration values and combining horizontal, lateral and vertical vibration values from three different 5-second intervals. Furthermore, there is no guidance for how to combine several 5-minute periods from the same test run into a single comfort index.

In addition, the P_{CT} and P_{DE} methods have certain weaknesses. The P_{CT} method has been validated for clothoids and linear cant transitions only. The application of the P_{CT} method may also become dubious if transition curves are separated by very short straight lines or circular curves: How long must an intermediate straight be in order to divide a reverse curve into two separate curves? (The same question arises for circular curves within compound curves.)

It should also be noted that the P_{CT} and P_{DE} functions are derived from the same test runs, with the same subjects and the same voting. The P_{DE} functions take into consideration 2-second average lateral acceleration and peak-to-peak acceleration within a 2-second window. The P_{CT} functions take into account 1-second average lateral acceleration and a change of lateral acceleration over one second, plus a minor influence of the roll velocity which is believed to have been (close to) zero on track segments where the P_{DE} functions were derived. Perhaps it would be possible to merge the two functions into a more general P function, applicable on all types of alignment elements.

Hence, an important conclusion is that even if a new European standard has been published, there is still room for further research in the area of ride comfort evaluation.

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