A ROAD SAFETY APPROACH FOR A NEW REVISION OF THE PORTUGUESE DESIGN GUIDELINES

António Lemonde de Macedo
Laboratório Nacional de Engenharia Civil, LNEC
Av. Do Brasil 101, 1070-066 LISBON Portugal
Tel: + 351 21 8443460, E-mail: almacedo@lnec.pt

João Lourenço Cardoso
Laboratório Nacional de Engenharia Civil, LNEC
Av. Do Brasil 101, 1070-066 LISBON Portugal
Tel: + 351 21 8443661, E-mail: joao.cardoso@lnec.pt

Carlos de Almeida Roque
Laboratório Nacional de Engenharia Civil, LNEC
Av. Do Brasil 101, 1070-066 LISBON Portugal
Tel: + 351 21 8443970, E-mail: croque@lnec.pt

ABSTRACT
The Portuguese road design guidelines have undergone periodical revisions, aiming at updating technical aspects of the geometric design of road elements and enlarging the field of their application to various types of roads and intersections. The National Laboratory for Civil Engineering (LNEC), through its Transportation Department, has provided scientific and technical support and advice to the road administrations along this process.

At the present stage, a proposal made by LNEC points out to the need for a thorough reformulation of the whole set of documents which are currently being used in Portugal as road design guidelines, in order to introduce a greater integration among them, and new technical advances based on scientific ground. A strategy to carry out that reformulation is being followed, which involves the setting up of an encompassing framework centred in a so called “base document” which contains common concepts and technical indications to which all the guidelines for specific types of roads must comply with.

In this paper a presentation is made on the main characteristics of the said “base document” prepared by LNEC, as well as the rationale underlying the introduction of a road safety approach into not only the conceptual frame but also the definition of road geometric design parameters and acceptable limit values, more closely related to the human component, which are derived, for example, from the assessment of driver’s behaviour characterization, using the results of a large number of measurements in Portuguese and other European road networks.

1 INTRODUCTION
The need for guidelines and other reference documents on good practice, directed to road design, has been apparent all along the XX Century and especially since the expansion of road traffic which occurred after the Second World War. The available documents for that purpose have evolved from sets of empirical rules based upon the practical experience brought by the construction of great extensions of roads, to technical specifications and standards, derived
from the application of experimental design methods and scientific approaches to the phenomena involved.

As far as the road geometry component is concerned, safety has long been recognized as one major design criteria and therefore progressively introduced in those guidelines.

In the case of Portugal, the National Roads Administration produced several road design guidelines in the past century. In the early 90’s a set of documents were published by this administration, referring not only to the geometric design of rural road segments, at grade intersections and interchanges, but also to road markings and signs. These guidelines have been in use since then, with no major changes as regards their basic structure and main concepts adopted. However, a process aiming at a revision related to the geometric design was initiated around ten years ago, as described in the following chapters 2 and 3, the latter being dedicated to its present stage with its focus on the so-called “base document” which has been prepared at LNEC.

The National Laboratory for Civil Engineering (LNEC), through its Transportation Department, has provided scientific and technical support and advice within the scope of the said process.

The expertise detained at LNEC in this area has been acquired along almost 40 years, through applied research, including the development of PhD thesis, and various specific traffic safety studies carried out for both public and private Portuguese entities. Over the last two decades an important enlargement of this activity has been achieved through the participation in joint research projects at the European level, among which the following have played an essential role for the subject under consideration: SAFESTAR (Safety Standards for Road Design and Redesign); RIPCORD-ISEREST (Road Infrastructure Safety Protection – Core Research and Development for Road Safety in Europe) and RISMET (Road Infrastructure Safety Management Evaluation Tools) (Macedo, 2006).

The engagement of LNEC in those joint research international projects has thereafter been transferred to the national level, through protocol agreements with road and traffic authorities, by which some useful results were tested and applied, with the necessary adaptations, to the specific conditions of the Portuguese road traffic system, including driving behaviour.

A particularly important result of the research carried out concerns the explicit consideration of safety criteria and related methodologies into the design of road infrastructures. Therefore within the final stage of the process undertaken for the revision of the Portuguese road geometric design guidelines, where a thorough reformulation was proposed, a major role is played by the road safety approach which was adopted, as presented in chapter 4, where, besides the conceptual background, some examples are given to illustrate present features of such approach.

As conclusive remarks, stated in chapter 5, the main aspects brought up in this paper are highlighted and mention is made to the foreseen developments that shall follow the revision of the national design guidelines, based upon the current use of the framework centred on the “base document”, after it has been validated and published by the competent authority.

2 THE REVISION OF THE PORTUGUESE ROAD DESIGN GUIDELINES

The revision process of the version, published in 1994, of the Portuguese Road Design Guidelines (JAE, 1994) started in 2001, and was carried out by LNEC through a collaboration agreement with the National Roads Administration. As the result of a very detailed appraisal of the guideline, several improvements were proposed on the content of its different chapters (Macedo and Cardoso, 2002). However, by then, no new version was published, which would incorporate those proposals.
This process was reinitiated in 2009, having also the participation of LNEC, through a contract with the National Institute for Road Infrastructures (InIR), comprising two lines of action.

The first line addressed the improvement of the existing guidelines, taking into consideration the previous work carried out by LNEC and further contributions from other sources, and incorporating not only specific modifications but also some subjects that needed updating, such as, for example, the assessment of geometric design consistency. This was accomplished in 2010, with the presentation of an up-dated version of the guidelines (Macedo and Cardoso, 2010).

The second line of action was based on the assumption that a thorough reformulation was needed of the whole set of documents that were currently applied as guidelines for the geometric design of roads and intersections. The underlying reason was that neither the structure nor the content of the existing guidelines, even after the adoption of a revised version as stated above, were able to fully comply with the state of the art attained by the progress of knowledge and practice in this field that occurred over the last two decades, as referred to in chapter 1. Besides the need of a new conceptual background, based on a road safety approach, some important basic elements for road design were still missing in the existing guidelines, which should be introduced, as related to design controls and criteria. Among the elements that were lacking, mention should be made to design vehicles, drivers’ physical and behavioural parameters and explicit design values for road surface characteristics.

For the development of this reformulation process, a strategy was proposed by LNEC for the case of the geometric component of road design, based on the setting up of a new framework for the respective guidelines. As a fundamental piece of this framework stands the so-called “base document”. The aim behind its elaboration was to put together and present in a structured and coherent way the general concepts and criteria, methodological (road safety) approaches and technical elements to be adopted in road geometric design, complying with scientific advances in this area.

The role of the “base document” is to serve as a common reference and guide to the making up and use of the other pieces of the proposed framework, which constitute a set of guidelines, pertaining each to a specific type of road infrastructure, as required by their distinctive characteristics, related either to road segments (motorways, single carriageway rural roads, urban streets, etc.), or to intersections (at grade, interchanges, roundabouts, etc.). Among these documents, most of them already exist which must be subjected to the necessary adjustments and updating in accordance with the “base document”, and some new ones ought to be developed accordingly, as, for example, the case of guidelines for the design of urban streets.

3 THE “BASE DOCUMENT” PREPARED BY LNEC

In June 2011 LNEC presented to InIR a preliminary version of the “base document” (Macedo et al., 2011) intended to fulfil the general objectives referred to in the preceding chapter. A number of additional requirements were taken into account in the preparation of that document, as follows:

To ensure a comprehensive field of application: to seek that the main concepts, criteria and technical recommendations for the geometric design of roads are of a general nature, not directed to a specific type of road or intersection;

To fill important gaps detected in current guidelines: to include the definition of updated standard characteristics to be considered at the project level, as, for example, those related to the road user, the vehicle and the road surface;
To rely on proven up-dated results of applied research in this area: to include explicit mention to the sources that were used, such as similar reference documents and other scientific and technical publications, issued by credible and competent entities;

To take into account the specificities of the national road system: to ensure that, in those cases where foreign specifications or design elements are adopted, they are adequate and compatible with the specific characteristics that are present in Portugal at the various aspects of the road traffic system, including the ones related to its users (drivers and pedestrians).

The “base document” is divided into three parts. Part I gives a general presentation of the document’s content, including background information, research carried out in this area, bibliographic references, objectives of the document, its structure and its foreseeable application in the scope of the new framework for road geometric design guidelines. Part II is dedicated to the main concepts that have been adopted, as well as to general criteria to be followed, within an approach to road design, which is able to respond to present demands of direct users of the guidelines and of society. Finally, Part III contains the essential technical elements, which are common to the design of the different types of roads and intersections.

Within the content of the “base document”, besides the reference to general design criteria, overall concepts of self-explaining and forgiving roads (see chapter 4.1) are introduced as the basis of a functional classification for the different Portuguese road networks and as guidance targets for the intervention of the road designer.

As design controls, the document presents the characterization of design vehicles (including their turning paths) and of road users, as regards not only drivers, through the main physical, physiological and behavioural aspects influencing the driving task (specific side studies being undertaken for considering the specificities of the Portuguese population; see an example in 4.2), but also pedestrians. The factors pertaining to the road infrastructure are addressed concerning the surface conditions, with a particular focus on the coefficients of friction. Special attention is also devoted to clear and unambiguous definitions of several design factors, such as speed (design speed, unimpeded speed), traffic parameters, and basic assumptions for the calculation of different visibility distances (stopping, obstacle avoidance, decision and passing).

The “base document” addresses several technical elements especially related to the geometric design of horizontal and vertical alignments, also based upon safety considerations, as in the example shown in chapter 4.3.

4 EXAMPLES RELATED TO THE ROAD SAFETY APPROACH

4.1 Towards self-explaining and forgiving roads
Road traffic is a complex system consisting of elements with high diversity of characteristics and whose interactions are poorly standardized and also not completely understood. The application of a systems’ approach to road safety leads to the recognition that human factors are key aspects in the operation of the traffic.

The concept of “self-explaining roads” stems from acknowledging that road environments that contain carefully selected key components and equipment may influence road user expectations as regards their own driving behaviour and the behaviour of other users, thus assisting their choice of appropriate driving manoeuvres and speeds. Ideally, on a self-explaining road there would be no need for speed limiting signs neither for danger warning signs (Matena et al., 2006).

At the planning and design level, functional categorization has been applied to roads managed by Portuguese central administration only. The categorization of roads under local administration is defined in each municipal plan, and there is no general accepted system.
Discrepancies between the national road network categories and those from local road networks are not uncommon, making it difficult for drivers to construct *a priori* expectations as regards desirable driving behaviour. On the other hand, the highway code defines four classes of roads (motorways, express roads, urban streets and other interurban roads) specifying general speed limits for each road class and special driving requirements for high speed roads. Interurban roads may have very different characteristics, as regards access control, geometric design (namely cross section and design speed) and traffic (local and long distance); however, a unique general speed limit applies to all these interurban roads, contributing to difficulties in developing *a priori* driving expectations.

To improve this background, a categorization applicable to all Portuguese roads was developed and proposed within the “base document”, as presented in Table 1.

The notion of “forgiving road” stems from the recognition that local control traffic system is the responsibility of human beings who will most certainly make mistakes, so it is important to mitigate the consequences of these errors by ensuring that they do not originate irrecoverable injuries. Ideally, accidents in a forgiving road do not result in killed or seriously injured victims (Matena *et al*., 2006).

<table>
<thead>
<tr>
<th>Table 1: Proposed categorization of Portuguese roads</th>
</tr>
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<tbody>
<tr>
<td><strong>Function</strong></td>
</tr>
<tr>
<td>Mobility</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>Distribution</td>
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<tr>
<td>Access</td>
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</tbody>
</table>

* n – Number of lanes per driving direction; ** IP – Main itinerary; IC – Complementary itinerary

With reference to the application of the forgiving road concept, the proposed “base document” does include general provisions for roadside design, which have already been detailed in two companion design guideline manuals, one defining requirements for obstacle free zone (Roque and Cardoso, 2011) and the other laying-out a cost-benefit procedure for supporting decisions regarding the need for safety barrier installation and type selection (Roque and Cardoso, 2010).

4.2 Driver’s eye height and sight distance criteria
Driving is a cognitively demanding task in which a substantial portion of the information to be processed is obtained visually. The ability to see the road environment in order to assess its
characteristics and observe potentially conflicting traffic is fundamental to traffic safety. Speed, human characteristics, unexpectedness of stimuli and the type of appropriate decisions and manoeuvres are relevant variables when assessing the amount of time required by drivers in each traffic situation.

A review of sight distance criteria was carried out, in order to check that relevant traffic situations are considered and to update the recommended basic parameters for each situation. Basically two broad types of traffic situation were considered (normal driving conditions and emergency situations), leading to the definition of four different sight distance parameters: stopping sight distance, sight distance to circumvent an obstacle, decision sight distance, and passing sight distance. Where available, such as in the case of driver’s eye height and of unimpeded speeds in each road class, Portuguese basic data were used.

The driver's eye height is an important parameter for setting sight distances. The correct assessment of this parameter contributes, therefore, to a geometric design which provides safety driving conditions. For inclusion in the “base document”, within the reformulation process of the Portuguese design guidelines, it was decided to carry out a complementary study to calculate its value according to present anthropometric characteristics of Portuguese citizens.

Disaggregated data from the USA (Helander, 2006) was compared with Portuguese data obtained by Padez (2007) in a study on secular trends in the average height of Portuguese males, measured at the time of mandatory military conscription.

Hence, the average height of 18 year old Portuguese male in 2010 was estimated by linear regression, based on data from Padez (2007). The resulting relation between the expected average height of Portuguese males and the observation year is calculated by:

\[ \text{Height} = 0.0898 \times \text{Year} - 7.8278 \]  \hspace{1cm} (1)

The correspondence between the data from the USA population (Helander, 2006) and Portuguese data was made to estimate body dimensions relevant to the determination of the height of the driver's eye, and was based on the estimated average height of Portuguese male with 18 years of age in 2010 (172.6 cm).

It is possible to estimate the reference driver's eye height (inside a vehicle) based on these body dimensions. Several percentiles for male and female distributions were calculated, the most unfavourable for establishing sight distances being the one for the female 5th percentile, which was selected as an important benchmark value for the design parameter.

The driving position recommended for modern cars was considered, as stated in recent international bibliography (Kyung and Nussbaum, 2009, Park et al., 2000, Sun et al., 2006).

The value obtained, considering postural angles defined by Kyung and Nussbaum (2009), is 0.82 m (see Figure 1). Note that the vehicle’s ground clearance (the distance from pavement surface to the lowest point of the driver's feet) must be added to this value.
No minimum limits for car ground clearance were identified in the consulted European Directives on car specifications. Hence, to estimate car ground clearance, technical specifications of common models in current Portuguese vehicle stock were collected and analysed. As a result the estimated value for drivers’ eye height was 104.5 cm (see Figure 1). The calculated value is very close to 105 cm, which was the one already stated in the previous edition of the road design standards (JAE, 1994); as a result, a decision was made to keep the existing value.

Speeds assumed for sight distance assessment and for decisions regarding horizontal curve radius were derived from observations carried out in several road sections of the Portuguese National Road Network, and are representative of the observed unimpeded speed on long tangents and typical horizontal curves. In Figure 2 the relations between speed and horizontal curve radii are presented for motorways (A), non-motorway dual carriageway roads (B), and several types of single carriageway roads (C – lane width greater than 7.75 m and paved shoulder; D – lane width greater than 7.75 m and non-paved shoulder; E – lane width between 6.00 m and 7.75 m, and paved shoulder; F – lane width between 6.00 m and 7.75 m, and non-paved shoulder; G – lane width smaller than 6.00 m, all types of shoulder).

Figure 1: Estimated Portuguese driver’s eye height.

Figure 2: Speed as function of road category, carriageway width and shoulder type.
4.3 Improving road design consistency

Horizontal road curves may create visibility, tracking and vehicle stability problems that increase the difficulty of driving tasks, as compared to the case of straight sections, thus contributing to a higher risk of lane departures that may lead to head-on collisions and collisions with roadside obstacles. In fact, road curves account for more than 28% of the accidents registered in Portuguese single carriageway interurban roads, resulting in more than 29% of the total number of fatal and serious injuries in that type of roads. Portuguese rural road links presented an overall accident rate on curves that is almost 50% higher than on tangents (Cardoso, 2001, and Cardoso, 2005).

From a safety point of view, it is important to detect road curves where driver expectancy violations may occur (the so called inconsistent road curves) in order to alert the unfamiliar drivers or to improve road characteristics in the approach sections to those curves. Visibility (how easy it is to perceive that there is a curve ahead and at what distance), readability (how easy it is for a driver to evaluate the curve geometry, in order to choose an appropriate speed) and skidding resistance (as resulting from friction coefficients and macro-texture) are some important characteristics that have significant impact in safety at curves (Cardoso, 1998). Roadside characteristics (especially the presence of dangerous obstacles near the carriageway) are also important, as regards run-off-the-road accident severity outcomes.

Several methods have been proposed internationally to address road consistency (Cardoso, 1997). The method adopted for inclusion in the “base document” was developed at LNEC, following driving behaviour observations on Portuguese roads and cross section accident modelling.

Basically, models for calculation of unimpeded speed profiles are used to estimate conformity of horizontal curves with driver expectancy, as measured by the agreement between speeds on a curve and on the previous tangent (or on the previous curve, when there is no tangent between two successive curves). Then, selected road characteristics and speed differentials between successive elements are used to estimate the expected accident risk in each curve and compare this value with the expected accident risk in a tangent section of equal length. These calculations are made using log-linear accident frequency models. Energy considerations and the ratio of expected accident risk (curve vs. tangent) are used to calculate an inconsistency factor; this factor, the change in speed while approaching a curve and the deceleration rate are combined to identify the consistency class of each curve (Table 2). A computer program was developed for practical application of this process (Cardoso, 2005).
Table 2: Classification of horizontal curve consistency (source: Cardoso, 2005).

<table>
<thead>
<tr>
<th>Consistency class*</th>
<th>Speed reduction</th>
<th>Deceleration rate</th>
<th>Inconsistency Factor ($FH$)</th>
<th>Type of road</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Paved shoulders</td>
</tr>
<tr>
<td>O</td>
<td>( \leq 5 \text{ km/h} )</td>
<td>( \leq 2 \text{ ms}^{-2} )</td>
<td>( \leq 2.5 )</td>
<td>( \leq 1.5 )</td>
</tr>
<tr>
<td>A</td>
<td>( &gt; 5 \text{ km/h} )</td>
<td>( \leq 3.0 )</td>
<td>( \leq 2.0 )</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>( \leq 4.0 )</td>
<td>( \leq 3.0 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>( \leq 8.0 )</td>
<td>( \leq 6.0 )</td>
<td>* - For classes ‘O’ to ‘C’, all three criteria (‘Speed reduction’, ‘Deceleration’ and ‘$FH$’) must be fulfilled; for class ‘D’, ‘Speed reduction’ and just one other criterion (‘Deceleration’ or ‘$FH$’) have to be satisfied.</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>( \leq 8.0 )</td>
<td>( &gt; 8.0 )</td>
<td>( &gt; 6.0 )</td>
<td></td>
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</tbody>
</table>

*Curves of consistency classes ‘B’ and ‘C’ are not accepted at the design stage for new roads, unless there is a strong justification, based on physical or economical feasibility; the same applies to the redesign of existing roads. In these cases, the road alignment has to be changed in such a way that lower approach speeds to the curve are obtained. Consistency class ‘D’ curves introduce exceptionally high speed reductions or they force drivers to very strong deceleration rates; these are serious inconsistencies which are not acceptable in new roads or in redesigned existing roads.

5 CONCLUSIVE REMARKS

The elaboration of the preliminary version of the “base document” that was delivered by LNEC to the National Institute for Road Infrastructures constitutes a major step towards the building up of the new framework envisaged for the Portuguese road design guidelines within a strategy set forth for the needed reformulation of the existing ones.

As described, and shown in some examples in this paper, three main levels of the whole subjects dealt by the guidelines were addressed in the scope of the “base document”. Starting with the conceptual and methodological level, going into the level of general design controls and criteria, and ending in the level where essential technical elements for the road geometric design are defined.

In order to contribute to a sustainable road safety goal applicable to the entire Portuguese road networks, a safety approach was used in each one of those levels, according to their specificity. At the first level the “self-explaining” and “forgiving road” concepts were introduced as two basic pillars for conducting the design tasks, and were also used as references for an overall proposal for the categorization of Portuguese roads which was included in the “base document”. At the other levels the use of explicit safety criteria and scientifically driven procedures was a common ground for the technical dispositions that were introduced throughout that same document.

As mentioned earlier the “base document” constitutes a central piece of the said framework. Therefore, after it has been approved by the competent authorities, further steps must be taken in order to ensure the accomplishment of its envisaged role with relation to the other components of that framework. These are the guidelines which apply to specific types of roads and intersections. The existing ones (e. g. for rural road segments; at-grade
intersections; interchanges; roundabouts) must be subject each to a revision in order to verify their compliance with what is specified by the “base document”, and shall experience the necessary adjustments (reformulation) for that purpose. The setting up of new guidelines that may be deemed necessary to fill existing gaps (e. g. for motorways and for urban streets) will benefit from the fact that the “base document” is already there. At the end an integrated and coherent set of good practice documents will constitute this framework, having a common conceptual backgrounds and technical references provided by their link and compliance to the “base document”.

Furthermore, there is a need for a continuous follow up of the developments introduced by new research results in the field under consideration, in order to periodically assess the validity and comprehensiveness of the main dispositions within the “base document”. Therefore the proposed framework must allow for the necessary flexibility in order to ensure that the up-dating of the guidelines is undertaken whenever deemed necessary.

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