Country report Germany

The new Generation of Design Guidelines for Roads and Motorways in Germany”

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Word count: 7,560 words text + 16 tables/figures x 250 words (each) = 11,560

Dresden, March 20th, 2015
ABSTRACT

Germany has recently finished the process of restructuring its whole system of design guidelines. This process is described in general and in addition with special attention to highways and roundabouts. (Guidelines for rural road design are introduced in a separate paper at the conference (1)). As a new principle roads are standardized in design classes and become self-explaining to suggest the road user the respective desired and correct behavior. This principle is applied for urban streets, rural highways, and freeways. Besides these rather basic ideas, the paper gives also an overview of the entire set of design standards and guidelines in Germany.

1 THE GERMAN ROAD TRANSPORT SYSTEM

Because of Germany’s central geographic location in Europe, road transport in the country is characterized by high proportions of cross-border and transit traffic. All indicators suggest that the level of traffic in terms of passenger and tone kilometers will continue to rise in the future. The highest growth will be in the road transport sector where, according to the most recent forecasts, traffic levels will increase by just less than 80 percent, with an even greater rise in long-distance road transport of as much as 84 percent. It is true that the financial and economic crisis considerably reduced the growth in traffic in 2009, but this effect is likely to be temporary.

The reasons for this growth are the continuing trend towards globalization with increasing international division of labor, which causes exports and imports to rise at a disproportionately high rate compared with GDP, and foreign trade as the main factor driving up tone kilometers. As a result of the further specialization of industry, the delivery of intermediate goods will also continue to increase.

The highly efficient German trunk road network currently comprises around 12,900 km of federal freeways and 40,000 km of federal highways, making it one of the densest trunk road networks in Europe. Since the reunification of Germany in 1990, over 2,100 km have been added to the freeway network. Around 1,800 km have been widened to six or more lanes. In addition, around 3,300 km of federal highways have been upgraded or constructed. This figure includes around 590 bypasses. (2) Although trunk roads only account for around 23 % of the total network (in the case of federal freeways this figure is as low as 6 %), just less than 50 % of all vehicle mileage is done on these roads, with over 30 % of all mileage being driven on federal freeways.

For many years now, there has been a continuous drop in the number of people killed on German roads. In 2013, 3,338 people were killed on roads in Germany. This was the lowest figure since official statistics were introduced in 1953 (2). Despite this encouragingly positive trend, the permanent evolution of road safety activities remains a key and indispensable concern. Despite all the technological developments, it is human beings, as road traffic stakeholders, who are always at the centre of the endeavors to enhance road safety.

In 2011 a new National Road Safety Program was developed. Its prime objective is to reflect the changed environment and new challenges in road traffic. This initiative will focus on, inter alia,
the safe mobility of senior citizens, the further improvement of safety on rural roads and the protection of vulnerable road users.

Today, it is difficult to imagine the federal freeways in Germany without road transport telematics. The traffic hotspots, in particular, are equipped with different types of traffic control system. These systems:

- harmonize the flow of traffic by means of variable speed limits;
- ensure a more balanced load on congested freeway networks by means of variable direction signs;
- enhance capacity for a limited period of time by allowing hard shoulder running;
- stabilize the flow of traffic on the main carriageway by using signals for ramp access control.

Our “Project Plan for Road Transport Telematics, 2010-2015” currently under revision includes further specific measures, which are being systematically implemented by the federal states' highway authorities.

In addition to enhancing the efficiency of road use, further upgrading schemes will be required if we are to manage future growth. The basis for the expansion and modernization of the German trunk road network is the Federal Transport Infrastructure Plan (FTIP), which covers the rail, road and waterway modes. A revised version of the current FTIP, which dates from 2003, will be released in 2015. This will also be the draft of the Act amending the Federal Trunk Roads Upgrading Act with the related requirement plan for federal trunk roads, which has to be passed by parliament (German Bundestag).

In order to maintain the high quality of the German transport infrastructure, and to be able to manage the forecast growth in passenger and freight traffic, a significantly larger amount must be invested in structural maintenance and in upgrading existing and constructing new infrastructure. The extension of the user pays principle will lead to greater independence from the budgetary situation of the Federal Government and create greater planning certainty for the financing of urgently needed transport infrastructure investment. (3)

In order to implement this project, an infrastructure charge is to be introduced for keepers of passenger cars and motor homes registered in and outside Germany alike for the use of German federal freeways and federal highways. Keepers of passenger cars and motor homes registered outside Germany will only have to pay to use federal freeways. The revenue generated by the infrastructure charge, reduced by the costs for the system, will be ring-fenced for investment in transport infrastructure. (3)

The infrastructure charge will have to be paid for one year by all keepers of motor vehicles registered in Germany. The price of the annual vignette for passenger cars will be calculated based on their engine capacity and environmental performance. (3)

The requirements for new road construction schemes under consideration, as reported by the 16 federal states, will be reviewed by the Federal Government on the basis of uniform criteria to determine whether they are plausible and constitute value for money. A macroeconomic benefit-cost analysis will be carried out on the basis of current forecast data for all capital investment projects under consideration in the new FTIP (around 2,500 trunk road projects nationwide).
This will result in a benefit-cost ratio (BCA), which must be greater than 1. Taking into account the funding available, the projects under consideration will then be assigned to one of two categories – the first priority category and the second priority category. In addition to the BCA, account will also be taken of network design, spatial planning, urban design and ecological aspects.

The final decision on the allocation of a project to the first priority category of the requirement plan for the federal trunk roads will be taken by the German Bundestag (parliament). This is the basic planning justification, legitimized at the highest level, for the highway authorities responsible for road construction in Germany.

A design will then be developed for the projects included in the requirement plan in accordance with the relevant design guidelines (5). Subsequently, the design will be reviewed in terms of its capacity and the level of service will be assessed in accordance with the Highway Capacity Manual (9) on the basis of the traffic forecast already determined for the benefit-cost analysis.

The construction work has been funded partly by revenue from HGV tolls, which has been available since 2005. In 2009, this innovative and unique tolling system raised toll revenue totaling around €4.3 billion, despite the decline in economic output resulting from the financial crisis.

The development of a modern system of rest areas designed to meet requirements also involves the provision of additional parking space for HGV drivers. The focus is on significantly increasing the number of HGV parking spaces along federal freeways. Between 2008 and 2010, 5,500 new HGV parking spaces were created at rest areas. Until now, further 5,000 HGV parking spaces were constructed.

In addition to road construction and widening, the structural maintenance of the existing federal trunk road network is of outstanding importance. The road mode is, after all, the lifeblood of the economy. This long-term objective calls for a structural maintenance policy that focuses on ensuring a high utility and safety value of transport infrastructure.

Upgrading and maintaining the road transport infrastructure in line with the respective requirements, necessitates around 800 road works sites lasting more than eight days and up to 50,000 daytime work sites on federal freeways each year. Experience has shown that road works cause around one third of all congestion on freeways.

To counter this phenomenon, optimized road works management is in place, which takes account of the impact on traffic when the road works sites are being planned. This involves planning and implementing road works lasting more than eight days such that they make full use of daylight and Saturday working.

2 THE SYSTEM OF DESIGN GUIDELINES

All guidelines for road design and operation in Germany are edited by FGSV (Road and Transportation Research Association), a private non-profit organization comparable to the TRB. Guidelines are elaborated by technical committees, the members of which are recruited from state and federal governmental organizations, private industry, consultants, universities, and
others. They all work on an honorary basis. The technical standards and specifications and all
other publications drafted by the FGSV are marketed by the organisation’s own publishing
company, FGSV Verlag (www.fgsv-verlag.de). The aim is to translate the most important
guidelines into English language in the near future. These guidelines and other technical
standards are regarded as the state-of-the-art, e.g. by administrations and by the courts. In this
sense their application, in principle, is mandatory. Moreover, the more important guidelines are
introduced by the federal DOT for the federal truck road network, i.e.: here they must be applied. Usually also the states DOTs make the application mandatory for state and county roads.
Usually, the guidelines offer a range of possible solutions and values in detail to provide to the road designer some options for technical decisions with respect to the specific situation under concern. Thus, the application of guidelines requires a well educated engineer and planner. However, in a majority of practical applications the guidelines should also be prepared for being used by less perfectly educated decision-makers.

The system of road design guidelines in Germany is matter of a complete reorganization in these times. The kernel of the design guidelines has always been divided into the areas of urban streets (), rural highways (), and freeways (5). In former times (up to the 1970s), as a substructure, cross sections, alignment, and intersections had their own guidelines with additional recommendations for pedestrian and bicycle facilities and a whole bunch of additional technical papers about matters like traffic calming, landscape planning, economic assessment, and many more details. The whole system was only understandable for insiders. 15 years ago a complete restructuring has been decided. The first new guidelines according to this system were launched in 2005. This system is illustrated in Figure 1. All design guidelines are subsequent to the Guideline for Integrated Network Planning (4).

The next lower level is represented by three main design guidelines comprising urban streets of all kinds, rural highways and freeways. The structure of each guideline is uniform and refers to:

- principles of road planning and design
- cross section design
- alignment design
- systems of intersections and intersection details
- facilities for non-motorized road users.

The purpose of this type-specific encompassing guidelines is, to follow the same sophistication regarding all details on each specific road type.

### 3 INTEGRATED NETWORK DESIGN

Over the years one basic principle turned out as a rather good idea. That is to categorize all roads in the network according to their primary function in the road network with

- the link categorization means the link between locations, cities, or regions (e.g. for freeways, rural highway, but also urban roads) and
- the link function level representing the importance of the connection (e.g. continental traffic, national, regional, local)

This principle is illustrated in Table 1.
TABLE 1 Road Categories (4) and Scope of RAA / RAL / RAST

<table>
<thead>
<tr>
<th>Link function level</th>
<th>Category group</th>
<th>Freeways</th>
<th>Rural roads</th>
<th>Trunk roads in non built-up areas</th>
<th>Trunk roads in built-up areas</th>
<th>Local roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AS</td>
<td>LS</td>
<td>VS</td>
<td>HS</td>
<td>ES</td>
</tr>
<tr>
<td>Continental</td>
<td>0</td>
<td>AS 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-continental</td>
<td>I</td>
<td>AS I</td>
<td>LS I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inter-regional</td>
<td>II</td>
<td>AS II</td>
<td>LS II</td>
<td>VS II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>III</td>
<td>-</td>
<td>LS III</td>
<td>VS III</td>
<td>HS III</td>
<td></td>
</tr>
<tr>
<td>Sub-regional</td>
<td>IV</td>
<td>-</td>
<td>LS IV</td>
<td></td>
<td>HS IV</td>
<td>ES IV</td>
</tr>
<tr>
<td>Local</td>
<td>V</td>
<td>-</td>
<td>LS V</td>
<td></td>
<td></td>
<td>ES V</td>
</tr>
</tbody>
</table>

Scope of application

<table>
<thead>
<tr>
<th>RAA</th>
<th>RAL</th>
<th>RAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS I</td>
<td>Designation of the category as it occurs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Problematic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Does not exist or is not justifiable</td>
<td></td>
</tr>
</tbody>
</table>

This categorization, as it is defined by RIN (4), has proofed to be a rather valuable tool for the determination of adequate design elements. In addition, it provides a useful tool for communication among planners and design engineers. Its application achieves the development of a hierarchical road network, which is the basis of all well functioning operation of roads according to its predominant function. Moreover, it contributes to adequate traffic safety. All the design guidelines determine their design elements along these categories.

4 NEW TECHNICAL FINDINGS

The traditional guidelines since the 1930s, when the first freeways were constructed in Germany, based their technical sophistication on the kinematics of road vehicles. First of all, there was a strong belief that the friction indices on wet road surface are the important physical basis of road traffic kinematics. These friction indices were assumed to depend on speed, which was mainly a result from stationary tire test machine measurement. The values of these indices were as low as 0.25 at a speed of 80 km/h. Beyond this speed no empirical data were available such that on extrapolation was necessary.

Two series of new measurements (10, 11) made clear that the traditional assumptions were, in fact, not justified. The authors performed measurements of decelerations with real cars on real freeways, which had been under traffic for several years. All tests were made on wet road surfaces where the thickness of the water film could be controlled. The important finding was that the maximum deceleration was not significantly affected by the level of speed as long as the tires fulfilled the usual technical requirements (intact tread). Moreover, the friction indices were
higher than expected. Of course, they differ systematically for vehicles with and without anti-
lock equipment (ABS).

As a consequence, the new guidelines assume constant deceleration rates of 3.7 m/s² for existing
roads to be renovated and for 4.3 m/s² for new roads.

These rather high values for skid resistance on wet road surface would result into minimum
design elements, like minimum radii for horizontal and vertical design elements, which become
unreasonable small. Their application would turn highways into roller coaster tracks. Thus, after
some calculations it becomes obvious that the kinematic principles cannot longer be maintained
as the basis of road design.

Moreover, several studies (e.g. 12) showed that drivers do not (and even cannot) follow the
trajectories which are assumed by kinematic derivations (like the assumption that drivers follow
the circular arc as it has been designed by the alignment). This is another reason why pure
kinematics does not lead to realistic modeling of driver’s behavior.

Also another project (13) about the influence of visibility in left turning curves of freeways (with
visibility limited by obstacles in the median) provided interesting insights. It was found that left
turning curves suffered more accidents than straight sections and even more than the right
turning curve in the opposite direction with the same curve radius. Left turning curves with
limited visibility also had higher accident occurrence than those without sight restrictions.

However, the type of accidents rather seldom was a collision with an obstacle on the roadway –
as it was expected. Instead, driving accidents where drivers lost control over their vehicles were
predominant. The conclusion from this is: The fast driver needs a specific sight distance to
handle the curvature of the road. Or in other words: to avoid driving accidents, not only curve
radii, superelevation, and cross-fall are important. Especially a good visibility along the road
helps to protect drivers against this type of accidents, which usually have severe consequences.

All these findings were not in accordance with the sophistication of the classical road
design guidelines. It was, however, not too easy to develop a new fundament. One obvious
consequence was that kinematics could no longer serve as the central idea.

5 DESIGN CLASSES

The answer to this dilemma has the name “design classes”. This term means: The road design
engineer should only offer a very limited number of road types to the road user. Within each type
the features of the road should be as uniform as possible. All features together should make the
road become “self explaining”. I.e. the driver learns from experience the typical combination of
elements for each type of road and which pattern of driving behavior matches with the
characteristics of the respective road type. The driver should be able to recognize the type at a
glance from the geometrical characteristics and the intersection design. This requires that the
typical elements within one type are rather similar and that the elements of different types should
differ as much as possible.

According to this sophistication the design classification of road types has been made and the
measures of all elements have been determined. Of course, these elements have also been
checked by kinematics and the designer will be encouraged to perform additional kinematic
checks after the whole design is finished, too. Nevertheless, the minimum values, e.g. the
minimum curve radii, are far above the kinematic requirements.

This concept of design classes is mainly applied to rural roads and freeways. But also
urban streets, in the new context, provide some similarities to this concept. The concept for rural
highways (14) is described especially in the conference proceedings by (1).

6 RURAL ROADS

The new design principle that emphasizes standardization and recognizability is expected
to be the key factor for an enhanced road safety. Both, standardization and recognizability, are
reached by the definition of only four road types (design classes) for rural roads (6). The design
classes depend on road link categorization and functional level. Design classes, with tight
specifications of design parameters, not only reduce the high variety but even support the
uniformity of road types (“recognizable”) and their distinctness to each other. On rural roads the
four classes specify the type of road operation, cross sections, the parameters of the alignment,
and the type of the junctions. However, each design class has different design parameters. In this
way, the driver should recognize the design class (“recognizability”) only looking at the design
parameters (Figure 2). Especially the always visible longitudinal road marking has a high
recognition value. Furthermore, design characteristics that affect driving speed are specific for
the particular design classes and encourage appropriate driving behavior.

The geometric design of roads and the corresponding design parameters are based on the
planning speed (Figure 2). This last is comparable with the design speed of former guidelines
and the estimated 85th-percentile speed on a road (1).

<table>
<thead>
<tr>
<th>Design class</th>
<th>Planning speed</th>
<th>Type of road operation</th>
<th>Cross sections</th>
<th>Alignment</th>
<th>Junctions</th>
</tr>
</thead>
<tbody>
<tr>
<td>EKL 1</td>
<td>110</td>
<td><img src="image1" alt="Car" /></td>
<td><img src="image2" alt="Cross sections" /></td>
<td><img src="image3" alt="Alignment" /></td>
<td><img src="image4" alt="Junctions" /></td>
</tr>
<tr>
<td>EKL 2</td>
<td>100</td>
<td><img src="image5" alt="Bike" /></td>
<td><img src="image6" alt="Cross sections" /></td>
<td><img src="image7" alt="Alignment" /></td>
<td><img src="image8" alt="Junctions" /></td>
</tr>
<tr>
<td>EKL 3</td>
<td>90</td>
<td><img src="image9" alt="Pedestrian+Bike" /></td>
<td><img src="image10" alt="Cross sections" /></td>
<td><img src="image11" alt="Alignment" /></td>
<td><img src="image12" alt="Junctions" /></td>
</tr>
<tr>
<td>EKL 4</td>
<td>70</td>
<td><img src="image13" alt="Motorcycle+Bike" /></td>
<td><img src="image14" alt="Cross sections" /></td>
<td><img src="image15" alt="Alignment" /></td>
<td><img src="image16" alt="Junctions" /></td>
</tr>
</tbody>
</table>

(*) Separate lanes for non-motorized traffic are recommends; however, it is not mandatory.

FIGURE 2 Design Classes and Design Characteristics (1)
FIGURE 3 Example for Rural Road Design Class EKL 1

FIGURE 4 Example for Rural Road Design Class EKL 2
FIGURE 5 Example for Rural Road Design Class EKL 3

FIGURE 6 Example for Rural Road Design Class EKL 4
7 FREEWAYS

7.1 Basic Principles

The German guidelines for the design of freeways (RAA, 5) cover rural and urban freeways (in German: Autobahn) as well as non-federal freeways (freeway-like roads). Freeways are technically defined as dual-carriageway, multi-lane, fully grade-separated road with no access from adjacent land. In accordance with the German Road Traffic Regulations the “freeway sign” is applied to Federal freeways only. Other non-Federal freeways are signposted using the “road restricted to motor vehicles” sign. In terms of jurisdiction non-federal freeways can also be Federal, state, district, or municipal highways. They might be characterized by lower lower design standards than Federal freeways of the same road category.

The guidelines describe basic principles and methods, design elements, together with considerations for the construction, for work zones, and extensions.

The design depends on the function of the freeway in accordance with RIN. According to RIN (4) RAA applies to

- category AS 0/I - long-distance freeways,
- category AS II – inter-regional or urban freeways.

Freeways have to serve the basic objectives mentioned above, as there are safety, traffic efficiency, and environmental issues. In addition, freeway design has to take into account construction maintenance and repair activities, since on average always more than 10 % of the network is covered with work zones. Thus, work zones are not an exception but they constitute something very normal. For freeways this aspect has considerable influence on the required width of the carriageway.

These requirements are expressed in several design classes which substitute the formerly guiding parameter design speed. Thus, the definitions for lane width, alignment, type of intersections etc. are only governed by the design classes. Input for the determination of the design class for a freeway is an assignment of the road category (AS in Table 1), the position of the freeway in relation to built-up areas, and the jurisdiction (Table 2).

Thus, Federal freeways are assigned to design class EKA 1 which is divided into EKA 1 A for long-distance freeways (AS 0/I) and EKA 1 B for inter-regional freeways. Since speeds on freeways in Germany are – in principle – unrestricted, rather high speeds should be possible on this type of freeways. However, the basic considerations are based on a maximum of 130 km/h - a value which is recommended as a maximum by the German Road Traffic Regulations. All design elements should offer a safe operation of traffic up to this speed. However, in case of any hazard lower speed limits can be posted. Only under strong restrictions due to the environment, an adaptation to these conditions by the use of some smaller design elements is possible together with adequate speed limits. These restrictions may be caused by ecological aspects, by existing built-up areas, or by the topology in a mountainous area. For freeways of design class EKA 2 (non-Federal freeways) smaller design elements can be applied. Therefore, they are easier to adapt to environmental restrictions.

Freeways of design class EKA 3 (urban freeways) are usually part of the urban street network, even if they should be integrated into the network of long-distance freeways. They tend...
to have shorter distances between intersections and they usually operate under speed limits of 100 km/h or lower. Caused by the urban environment, they are subject to significant restrictions. Some of the external conditions for different classes are given in Table 3. The design class should remain constant over longer distances. As a rule, a change should only jump by one class. In such cases, the transition needs special attention and should be obvious to the driver. The design class determines design features and minimal or recommended parameters for design elements. Thus, freeways of different design classes should provide different road characteristics. The design class determines

- standard cross sections,
- limiting and recommended parameters imposed by safety requirements, driving dynamics, and economy,
- basic forms of and distances between junctions,
- speed limits below recommended speed, if applicable.

<table>
<thead>
<tr>
<th>TABLE 2 DESIGN CLASSES FOR FREEWAYS (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road category</td>
</tr>
<tr>
<td>Position in relation to built-up areas</td>
</tr>
<tr>
<td>Jurisdiction</td>
</tr>
<tr>
<td>Designation</td>
</tr>
<tr>
<td>Design class</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 3 FREEWAY DESIGN CLASSES AND THEIR FEATURES (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design class</td>
</tr>
<tr>
<td>Designation</td>
</tr>
<tr>
<td>Maximum permissible speed</td>
</tr>
<tr>
<td>Recommended distance between junctions</td>
</tr>
<tr>
<td>Work zone layout on four-lane roads</td>
</tr>
</tbody>
</table>
6.2 Cross Sections

Freeway cross sections are determined by considerations of safety, quality of service as well as construction, maintenance, and reconstruction. The number of lanes and, thus, the choice of the standard cross section (RQ) are determined by the predicted traffic demands to achieve the desired quality of service in accordance with the German Highway Capacity Manual (9).

Cross sections of freeways comprise several elements with distinct dimensions. Their dimensions for design classes EKA 1 A and EKA 1 B are shown in Table 4. Thus, typical cross sections are denominated by their crown width (Figure 7). The layout in work zones indicates the number of narrowed lanes which are operated on one carriageway of the freeway during reconstruction or larger works of maintenance (e.g. 3+1 = 3 lanes on one carriageway + 1 lane on the carriageway of the work zone). “Shoulder” denotes the space between the lanes on the outside and the next element. It carries the lateral lane markings and it contributes to a space for emergency stopping. “Hard shoulder” is an additional lane which is only allowed to be used for emergency stopping as it also serves for enabling maintenance or emergency access for police and fire brigade.

**TABLE 4 Elements of Cross Sections for Design Classes EKA 1 A and B**

<table>
<thead>
<tr>
<th>Cross section</th>
<th>lanes</th>
<th>Layout in work zones</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lane [m]</td>
<td>Side strip [m]</td>
</tr>
<tr>
<td>RQ 43,5</td>
<td>8</td>
<td>6+0</td>
<td>3,75/3,50</td>
</tr>
<tr>
<td>RQ 36</td>
<td>6</td>
<td>5+1</td>
<td>3,75/3,50</td>
</tr>
<tr>
<td>RQ 31</td>
<td>4</td>
<td>4+0</td>
<td>3,75</td>
</tr>
</tbody>
</table>

FIGURE 7 Cross Sections for Design Classes EKA 1 A and B (5)

Of course, the detailed justification of the cross section is based on traffic engineering considerations according to the manual HBS (9). For a preliminary selection, however, it is
possible to use a cross section with 4 lanes until an AADT of 65,000 vehicles per day and with 6 lanes until 100,000 vehicles per day.

7.3 Freeway Alignment

Values for design elements for freeway alignments are given in Table 5.

The length of a straight in the horizontal alignment is recommended to be less than 2000 m. The radius of arcs has a lower limit which is determined by kinematics for EKA 2 and EKA 3. For EKA 1 A a higher value has been selected due to current practice and to avoid visibility restrictions on the direction with a left turning curve. In order to make the drivers notice the change of the direction, arcs must have a minimal length $L_{\text{min}}$.

The transition between straights and circular curves as well as between different circular curves shall be in the form of a clothoid. Lower limits for the parameter of the clothoid ($A_{\text{min}}$) result from the requirement, that the transition curve is visible to the driver and it includes the required ramp for changing the superelevation of the carriageway.

For the gradients, values below 4 % are favorable due to safety and traffic performance aspects. On the other hand, larger gradients allow for improved adaptation to the terrain and contribute to lower construction costs. As a compromise the allowed gradients have been increased compared to the former guidelines. Ascents longer than 500 m and steeper than 2.0 % are to be checked for the applicability of extra lanes in accordance with the HBS (9). In tunnels, the maximum gradient should always be less than 4.0 %, if possible, or less than 2.5 % in long tunnels.

<table>
<thead>
<tr>
<th>Design class</th>
<th>minimum horizontal radius $R_{\text{min}}$ [m]</th>
<th>minimum length of an arc $L_{\text{min}}$ [m]</th>
<th>Minimum parameter for clothoids $A_{\text{min}}$ [m]</th>
<th>maximum gradient $s$ [%]</th>
<th>minimum radius for crests $H_{K}$ [m]</th>
<th>minimum radius for sags $H_{W}$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EKA 1 A</td>
<td>900</td>
<td>75</td>
<td>300</td>
<td>4.0</td>
<td>13.000</td>
<td>8.800</td>
</tr>
<tr>
<td>EKA 1 B</td>
<td>720</td>
<td>75</td>
<td>240</td>
<td>4.5</td>
<td>10.000</td>
<td>5.700</td>
</tr>
<tr>
<td>EKA 2</td>
<td>470</td>
<td>55</td>
<td>160</td>
<td>4.5</td>
<td>5.000</td>
<td>4.000</td>
</tr>
<tr>
<td>EKA 3</td>
<td>280</td>
<td>55</td>
<td>90</td>
<td>6.0</td>
<td>3.000</td>
<td>2.600</td>
</tr>
</tbody>
</table>

Radii of crests and sags should be chosen in a way that they, together with the elements of the horizontal alignment, appear in a well-balanced three-dimensional alignment. Moreover, proper stopping sight distances should be achieved at anytime. On the other hand, large values for crest or sag radius lead to consumption of landscape and, thus, harm the environment. The minimum radius given in Table 5 allow for a sufficient stopping sight distance – even along sections below bridges - and for a visually attractive alignment. In special cases crest radius can be undercut (e.g. together with horizontal curvature or short crests).
For road safety and traffic quality, sufficient sight distance is a prerequisite. The purpose of doing so is to give the driver enough time to stop before a hazard (like an obstacle on the road), it provides - as a controlling element of road design - information and orientation for the driver about the road section ahead. Thus, sufficient sight distance is an important feature for drivers’ comfort and traffic safety.

The required sight distances are determined as stopping sight distance in wet conditions, which is the distance travelled by a driver before he comes to a stop ahead of an obstacle which might suddenly occur. It comprises the distance travelled during reaction time and braking distance. Particularities of driver behavior and attentiveness on freeways are taken into account. The required stopping sight distances for freeways of the design class EKA 1 is f.e. 240 m with a gradient of 0%.

### 7.4 Median

The purpose of the freeways median is to separate opposing traffic between both directions. The median provides space for restraint systems, for plants, and for pillars of bridges and signposts. In former guidelines (before 1996) medians as a standard measure had a width of 4 m. In the guidelines from 1996 their width was reduced to 3.5 m in order to save investment costs. With the current guideline the standard width returned to 4 m, since the reduction leads to a couple of problems. In Germany, no emergence lanes are offered along the median – also not in case of wider roadways.

The purpose of vehicle restraint systems is to minimize the consequences of accidents as much as possible. Vehicle restraint systems are applied in accordance with the guideline RPS. Furthermore, the systems have to comply with European norms (EN 1317). Vehicle restraint systems are either rigid systems (e.g. concrete barriers) which bounce colliding vehicles back onto the road, or deformable systems (e.g. steel barriers) having a more energy absorbing decelerating effect. Concrete Systems are in use mainly on recently built or renewed freeways with more than 60,000 vehicles per day (4 lanes) or 70,000 vehicles per day (6 lanes for both directions). For such a large traffic demand concrete barriers are favorable from an economic point of view since they require fewer repairs than steal barriers and, thus, cause less congestion in the event of repairs. Steel barriers are usually 1.5 m wide. Including the space needed for displacement or deflection they require median of 4 m width. Also for safety barriers along pillars of bridges and for a proper protection of pillars against a crash by a truck a 4 m wide median is desirable.

Plants in the median requires special care. On straight sections plants like shrubs and hedges offer anti-glare protection during night time. Here they are desirable. On the other hand, in curves plants could reduce sight distance. In any way, plants generate a considerable effort in terms of maintenance leading to disturbance of traffic. To grow properly plants require a minimum width of green area, which is more in the range of 4 m than lower.

### 7.5 Road Works

During maintenance or reconstruction the closing of parts of the freeway may become necessary. In the interest of safety it is then desirable to concentrate the traffic from both directions on one
of the two carriageways. Solutions where one lane of traffic remains on the side of the work zone (x+1) should be avoided due to safety and cost reasons. Moreover, the requirements for guiding the traffic through work zones increased according to the needs of safety. For instance, a physical separation of traffic from both directions is needed, e.g. by a steel barrier. Therefore, e.g. the width of a 4-lane freeway (RQ 31) is determined by the required width of the 4+0 layout of work zones with a paved width of 12 m. Also the thresholds for the application of RQ 28 in design class EKA 2 and the definition of the width on bridges with RQ 31 or RQ 28 are determined by work zone requirements.

7.6 Temporary Hard Shoulder Running

Hard shoulders are an important part of a freeway. They contribute to safety as they allow to store a vehicle broken down offside from the through traffic. They also provide space for maintenance activities and for a fast access of safety services to accident sites. Moreover, in case of accidents or maintenance work they help to keep the traffic flowing. In this sense, they are indispensable on a high performance freeway.

On the other hand, in case of frequently oversaturated traffic conditions there is a lot of temptation to change a paved shoulder into an normal traffic lane to provide additional capacity without much extra cost. Of course, this has happened over the years with increasing traffic demand at many locations within the freeway network. Recently, also solutions have been established for a temporary hard shoulder running. Indicated by variable message signs (Figure 8 and Figure 9), the hard shoulder is opened for traffic during peak hours. Such a step requires a lot of redesign (e.g. at the exits and entries), of reconstruction (e.g. to make the surface construction fit to carry heavy and fast traffic), and of jurisdictional considerations. Also the question how reliably vehicles standing on the hard shoulder should be detected before opening plays an important role. A set of regulations has been developed, which conditions must be fulfilled and how this is going to be organized. Meanwhile, one longer section of the 6-lane freeway (3 lanes for each direction) A 5 north of Frankfurt, thus can be converted into 4-lane operation for both directions over a length of 30 km, which contributed to a significant reduction of congestion on that freeway.
FIGURE 8 Hard Shoulder Running on the A 9 Freeway.

To enable this temporary use, a specific sign has been introduced into the German Road Traffic Regulation indicating that the shoulder should be used like the right lane.

FIGURE 9 Z 223 StVO Driving on Emergency Lane

(Z 223.1 „driving“ / Z 223.2 „no driving“ / Z 223.3 „change on main lane“)

8 ROUNDABOUTS

Roundabouts as a specific type of intersection have received growing attraction among planners and by the public over the last 25 years. Germany has made a rather careful development on this area compared with other countries on the European continent. It has not uncritically introduced roundabouts along a wide front. Instead investigations have been made with different types step by step. Meanwhile, however, the number of new roundabouts seems to be in the range of 4,000 (there is no official or reliable counting).

Here only some of the important messages should be mentioned:

Single-lane roundabouts (1 lane on the entries, 1 lane on the circle, 1 lane exits) are the most attractive form of roundabouts. They are the safest type of intersection among all others.
alternatives. They are also attractive due to traffic performance, costs, and urban design quality.

They can carry up to 25,000 vehicles per day.

Mini-roundabouts come rather close to these qualities. They are only allowed to be used in urban areas. Their capacity can be as high as 20,000 vehicles per day. The central island should be slightly elevated above the road surface (i.e.: no minis just by road marking).

Compact two-lane roundabouts with diameters between 40 and 60 m and an 8 – 10 m wide circle are a useful solution both for rural and urban areas. They come up to a daily capacity of 32,000 vehicles per day. It is most important to avoid bicycle traffic on this type of intersection.

Larger 2-lane roundabouts are not favored since they are limited in capacity to around 40,000 vehicles per day and since they provide higher risks. In no case, two-lane exits should be operated. Also flaring of entries is not favored at any type of roundabout.

Turbo-roundabout is a term which goes back to engineers in Netherlands, especially Bertus Fortuijn. Independently from that source turbos had also been developed in Germany. A prototype is the intersection in Baden-Baden (cf. 16). A turbo-roundabout is a roundabout with alternating numbers of lanes on the circle (in Germany only 1 or 2 lanes). The characteristic properties are that the addition of a lane is only achieved by adjoining the lane on the inner side opposite from an entry. Subtracting of a lane can be either performed as a normal lane drop or by a two-lane exit where the right lane must leave into the exit. Thus, the typical arrangements are type-1 exits and entries. Using only the defined types there is no need for drivers to change lanes on the circle. In consequence it could also be defined: A Turbo-roundabout is a kind of circular intersection where lane changes on the circular roadway are completely avoided. (17)

For the US reader it may be strange that this type of a roundabout is treated with such notice as a type of its own since in the US roundabouts like these are implemented without giving them a special name. (16)
All the daily capacities, mentioned above, must be confirmed for each specific case by
detailed capacity calculations since the real capacity and performance is much depending on the
traffic pattern of the individual movements. Here, one of the lessons learned is that there are
important differences between capacities of roundabouts between countries due to specific
German Road Traffic Regulations and different driving cultures. Details of the German
roundabout design policy are documented in the roundabout guideline launched in 2006 (18).

10 CONCLUSIONS

Guidelines are subject to continuous change and development. At the beginning, after the
first World Road Congress in 1908, emphasis was put mainly on the geometry of single vehicles
(motor vehicles, long horse carts). Starting in the 1920ies and 1930ies, fast-moving motor
vehicles requiring consideration of driving dynamics have been determining the guidelines. In
our days the traffic flow dynamics of masses of cars and trucks interacting with each other are in
the focus of design considerations.

At all times in the past the traffic safety has enjoyed the highest degree of attention,
which is also the case for the new design guidelines in Germany. Also, environmental issues are
within our awareness. Integration of roads into their environment in an ecologically sensible way
has become a major topic in the guidelines.
In Germany, at present, a completely new sophistication of road design guidelines is being operated. Although the questions of driving kinematics still have to be observed in the background, the apparent principle has become the design class with a specific shaping for urban streets, rural highways, and freeways. For all of these three kinds of roads a new guideline was launched between 2006 and 2012. Principles like readability or self-explaining properties of the road are receiving high importance.

It has to be admitted that these principles are now set into practice mainly by engineers. Our next goal will be a better understanding of human factors for an improved consideration of psycho-physiological properties of drivers in order to include human factors into design models more systematically. Research activities of this kind are already going on. This should also improve our potential to design roads which provide better sustainability, both in an ecological sense as well as regarding the functioning of the road from the aspects of safety, economics and social effects.

Moreover, there is some development of improved technical design methods, e.g. in connection with Computer Aided Design methods. Some emphasis is put on the better visualization of highway design. Thus should both contribute to continuity of highway design for the drivers as well as for improving the integration of roads into landscapes and townscapes.

Another point which makes planners and politicians in Germany concerned is the fact that Germany, like several European countries, has to face some changes regarding the demoscopic characteristics of its population. Most forecasts predict a reduced population for the longer future (i.e. from 82 million in 2004 to ≈ 75 million in 2030). Together with this, the proportion of elderly people will continuously grow. It is evident that this development will have consequences on the required amount of transportation infrastructure as well as on the kind of transportation facilities and its qualities. Nevertheless, the specific consequences of this development are not yet evident completely. Of course, these evolutions have also significant economic aspects. Recently a growing public discussion arises around this circle of questions.

REFERENCES


