SAFE DESIGN OF RURAL ROADS BY NORMALIZED ROAD CHARACTERISTICS

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Abstract

Within the project "safe design of rural roads by normalized road characteristics" the TU Berlin was researching what road design is affecting driving behaviour and road safety positively. The project aims are providing self-explaining and recognizable roads and therefore increasing road safety by creating design classes. Based on detailed accident analysis´ the design classes were derived. Besides the cross-sections with their road markings, the junction design and operation and the alignment were considered within the deliberations of safe design classes.

The driving behaviour was examined in with/without and before/after situations on real roads. The empiric analysis consisted of over 10.000 km tracking and fielding driving on 30 different roads. Furthermore the detected self-explaining roads were analyzed in the driving simulator of the TU Berlin. To ascertain the effect of these new kinds of roads they were compared with real roads implemented into the driving simulator.

Besides the driving speed, the acceleration and the lane keeping were measured over the stretch and locally on the real road and the driving simulator.

The results of the project show that the driving behaviour and therefore the road safety are influenced by the road design. Especially a new single-lane cross section for low volume roads showed positive results. Overall, appropriate combinations of cross sections and junctions with the alignment in mind affect the driving speed and lane keeping and therefore the road safety positively.

1 Current situation and course of action

The standard designs of rural roads vary a lot. The question which road characteristics will lead to a safe driving behaviour has yet to be answered. So far various studies have conducted research on specific road design elements, but have not been able to give an answer to the questions asked here. One approach to achieve a high quality road network is the standardisation of certain road types, which are supposed to have similar road characteristics within their category, but show significant differences towards the other road types.
In the course of the development of the new guidelines for rural roads, the "Richtlinien für die Anlage von Landstraßen (RAL)" [1], the aim is to provide self-explaining and recognizable road types for motorists. According to the new RAL [1] rural roads are being classified by traffic relevance into one of four design classes.
Thus, the designs of the cross-section and junction as well as the corresponding alignment are playing a decisive role. Expectations are that the general RAL [1] goals of normalizing rural roads, and through this positively influencing driver behaviour, will be enhanced by using characteristic designs.
During the project "Safe design of rural roads by normalized road characteristics" [3] various road types were analyzed to understand their influence on poor driving behaviour. The road types consist of a suitable combination of cross-section and junction designs.
Following accident analysis applicable study samples were selected. Driving behaviour was evaluated by driving speed and lane keeping behaviour. For this purpose profiles were created, local measurements were taken and tests were conducted in the driving simulator. Different road markings on various alignment elements were compared with one another. In addition to real and driving behaviour, optimized road types were test driven by subjects and the results were analyzed.
This paper contains the essential results of the design class 4 - the low volume roads.

2 Objective

The aim of the project is to gain verified knowledge about driving behaviour on rural roads. The results will allow to give advice regarding standardized road types, which should be preferably used for certain design classes. The concentration on a few road types should lead to better adaptation of driving behaviour and therefore an increase in road safety.

The road types do not only apply to alignment and junctions, but also to operational measures such as road markings or traffic signing for speed limits. Only by noticing the road characteristics the road type and appropriate driving behaviour should become obvious to the driver. This study is primarily analyzing how the road types should be designed and how the desired driving behaviour can be achieved. If the worst comes true an improved predictability of a road characteristic could lead to higher speeds, because the driver is sure about what is ahead of him. Although many studies and models about influencing factors such as cross-section width or bendiness exist (though mainly out-of-date), studies about multi-causal relations are still in their infancies. Particularly the question whether different road types show different driving behaviour or whether the driving behaviour consists of a cross-section typical driving behaviour and the sphere of influence of the junction (i.e. plus/minus 500 m) or whether the complete road characteristic including the surroundings is the influencing factor has not been answered yet.

The overall goal of the research is to gain information about the driving behaviour along the standardized road types. The design category oriented layout of rural roads is aiming to homogenise the used design features of the cross-section, the junctions and the alignment to advise the road user to adapt his driving behaviour.

3 Definition of road types

The suitable road types were preselected based on the current state of the discussion in the task force 2.2.1 of the German Road and Transportation Research Association (FGSV) „Designing new rural roads“, which classifies four different categories.

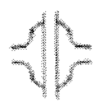
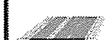
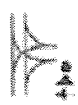
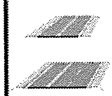
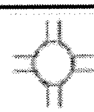
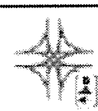
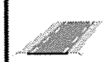
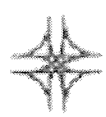
class	function	type	cross section	preferred intersection	alignment	regulations	suitable speed [km/h / miles/h]
1	long distance traffic	1			generous	no agricultural traffic no bikes no access to private properties	110
		2					
2	inter-regional traffic	3			semi generous	no bikes no access to private properties	100
		4					
3	regional traffic	5			semi adapted	if necessary: no bikes	90
		6					
4	local traffic	7			adapted	none	70

Fig. 1: Characteristics of the design classes

The main demands and goals of the separate road types were defined based on their role in the network (level of connection). On the one hand they are supposed to fulfil their regional development function with high road safety and a reasonable level of service and on the other hand they have to guarantee a low cost but sustainable protection of the environment and the surroundings. The consideration of the goals has to depend on the importance of the rural road for the network. This has to be the case because the often competing demands that the roads have to meet depend on their level of connection.

In the target field of road safety the goals of safe horizontal alignment, safe turning and crossing, safe passing and overtaking and safe roadside could be deduced from the number and severance of the accidents in a conducted accident analysis. These goals can be met with a variation of measures. By using uniform road characteristics in cross-sections, alignment (radii sequences in particular), type of operation, overtaking concept and intersection layout the appropriate driving speed should become apparent to the driver. Considering these results the design classes now contain characteristic elements in the areas alignment, cross-section design, intersection design, operation type and roadside furniture. Based on the network function four design classes consisting of a total of seven road types were classified.

4 Methodology of measuring the driving behaviour

Driving behaviour as such cannot be described and must therefore be determined with the use of indicators. For this purpose three different parameter categories were used. The vehicle born parameters consist of parameters along the section and cross-section as well as the parameters on the driver's side of the vehicle. The vehicle born data can be split into longitudinal control (speed, acceleration and deceleration) and the transverse control (lateral acceleration, lane keeping).

The empirical studies about driving behaviour have been conducted using two different methods. On the one hand local measurements were taken at certain locations along the test track. Relevant for the microscopic driving behaviour was data concerning the speed and lane keeping. On the other hand the driving behaviour of a single

vehicle was monitored with the following-car technique along the entire test track.
In the course of the empirical research radar meters (traffic flow, vehicle class and speed), video cameras equipped for video interpretation (lane keeping) and a test vehicle for the following-car technique (speed, acceleration and lane keeping) of the Department for Road Planning and Road Operating of the TU Berlin were available.
Microscopic data from both techniques were collected and statistically merged to macroscopic data. Earlier studies have shown that a sample size of 100 vehicles in free flowing traffic for the stationary measurements and 20 to 30 trips in each direction are sufficient. Furthermore the comparison with the results from the stationary measurements showed satisfactory representativeness.
The analysis of the empirical research was carried out using the aggregated data from speed, acceleration and lane keeping profiles. Furthermore the raw data were analyzed statistically to verify the reliability of the conclusions or at least deduce observable trends.

4.1 Test tracks

For the empirical research suitable test tracks were selected on the bases of a macroscopic accident analysis. For the differentiation of the test tracks the definitions of road types as classified above were used (see figure 1). The sections of road finally chosen were those with the highest achievement of objectives based on the criteria which had been previously defined. At least three test tracks for each road class were examined. The catalogue of criteria developed for the selection of the test tracks to ease the search for suitable test tracks and to allow an evaluation of achievement of objectives contained f.e. a specific length of the section, at least two junctions of the same type, no links inside urban area, no special road features along the stretch (i.e. tunnel and bridges), no poor road surface conditions and no longitudinal slopes over 4.0 %.
In addition none of the stretches which had already shown a high accident rate in the preliminary accident analysis were selected.

A further criterion was the existing traffic flow on the test tracks. Extremely low traffic would extend the time and effort considerably, heavy traffic would not allow reasonable conclusion about the individual behaviour of the road user as they are driving in a forced flow. For this reason test tracks with a medium flow of traffic were selected. Another vital condition was that no long-term traffic influencing road works were undertaken during the reference period of the accident analysis (2005 to 2007) or while any measurements were taken.

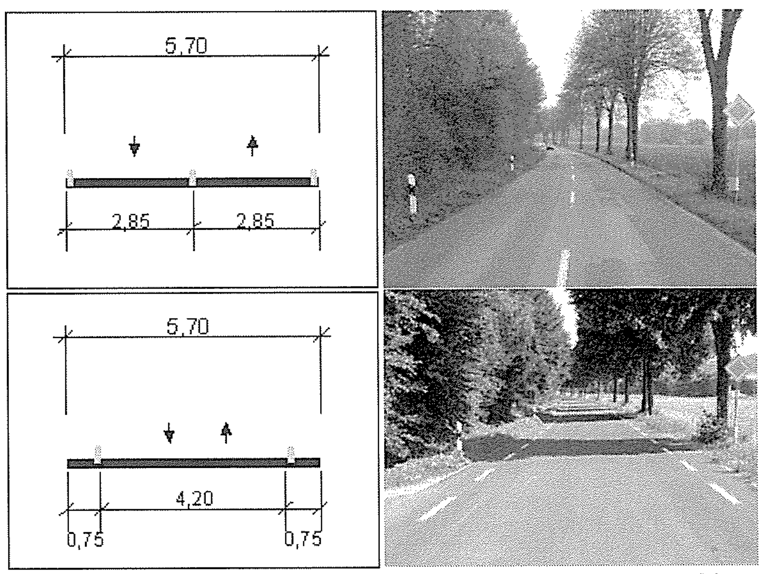


Fig. 2: Test track before (top) and after (bottom) the remarking

4.3 Test track for the before/after study of the design class 4

In co-operation with the federal state authority for road construction and transportation of Lower Saxony – division Hamlin a suitable test track for road type 7 was found. After repaving this stretch of road it was the first in the country that the new road markings according to the new RAL [1] were applied. The road markings consist of a broken line near the edges of the road.

The test track has a total length of 1.2 km and is part of the local road between the villages Höfingen and Fischbeck northwest of Hanover. The road contains no junctions. The daily traffic has a volume of about 1.800 vehicles / day. The amount of heavy vehicles is about 90 vehicles / day what is about 5 %. The track has no signed speed limit what regulates it to 100 km/h. The existing cross-section has a carriageway width of 5.70 m. The current road marking existed of a solid edge line and a spaced centre line (3 m length, S/L = 1/2). The old edge marking was slightly to be seen. After the renewal the marking, after the RAL [1], consisted of two broken edge lines with an offset of 0.75 m from the edge (2 m line length, S/L = 1/1).
Exemplary the results of the before/after study of the design class 4 should show the positive effects of indicating normalized roads.

4.4 Driving behaviour on low volume roads

The speed profiles on the test track are shown in figure 3. The profiles reflect the expected influence of the alignment. A speed influencing the area with the radii of about 200 m can be seen. Interesting is though that no matter what level of driving speed exists the same reduction occurs.

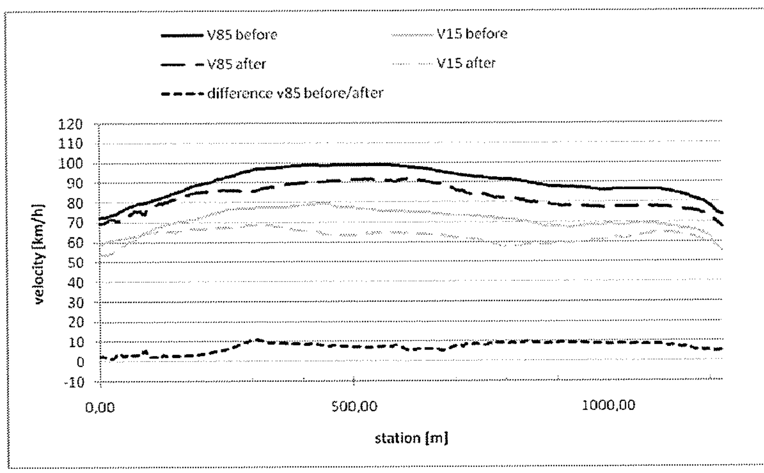


Fig. 3: Speed profile, speed differences of the test track

The average speed reduction for all percentile speed profiles were about 10 km/h for one direction. The other direction which already had a lower speed level in the before-situation showed a less noticeable speed reduction. For both directions though lower entering speeds in the villages could be ascertained. The local measurements confirm those results. They also show a reduction of the speed for the after-situation by about 10 %.
The lane keeping analysis at a certain station with an even alignment resulted in the expected way. In the before-situation all drivers kept their vehicles totally on their own lane. In the after-situation the vehicles are driving about 0.3 m further to the left. Furthermore the shoulder is not getting used for the free driving. Just in passing situations with oncoming traffic some drivers equivocate on the shoulder.

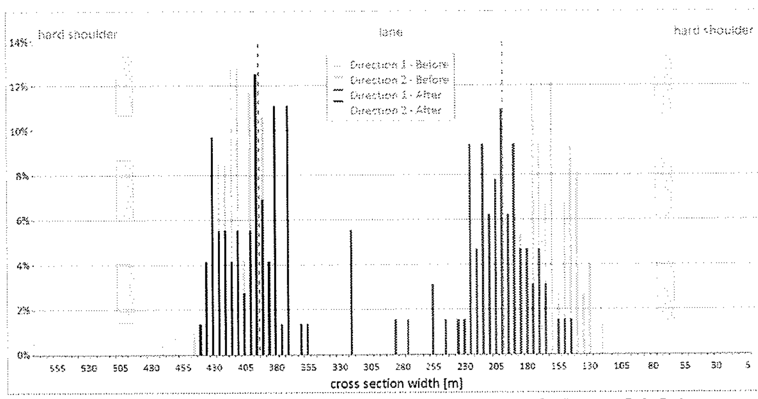


Fig. 4: local lane keeping behavior (center of the vehicle) at an even course

The lane keeping profiles show similar results. One of the major investigation objectives was to ascertain that the lane keeping in curves (especially in curves to the left) for the after-situation will not bring any problems with oncoming traffic. The profiles prove that the lane keeping in curves to the left differs by the sight distance. If the drivers have low sight distances their lane keeping stays along the broken edge line. For adequate sight distances they drive further to the left and so far cut the curve. Therefore it can be summarized that the new road marking does not result in a lower safety standard for situations with oncoming traffic.

5 Methodology of the tests in the driving simulator

As a foundation for the tests in the simulator the existing knowledge about the composition of suitable road types was utilised. The defined road types were programmed for the tests in the simulator. They had to be driving behaviour optimised and include the requested road characteristics. A total of five different road types were analyzed (Fig. 1). For comparison five real sections, which had been analyzed during the empirical research were integrated into the tests.
This allows an evaluation of the driving simulator comparing the real sections driven in the simulator and in situ on the one hand and a comparison between the real sections and the driving behaviour optimised sections on the other.

Fig. 5: characteristic cross-sections of design class 4

The five sections of each type consist of one section per design class. For design class 3 two separate sections with equal alignment but different junction design exist due to having to analyze single level junctions and roundabouts separately.
In addition to the parameters defined in Figure 1 with basic types of road markings and marker posts variations of road markings e.g. in design class 4 were analyzed. Further variable parameters were integrated into the driving simulator. Other vehicles with independent behaviour and the necessary coordination of signals were added to the

simulation in the course of this project. The traffic situation was hereby initiated location or event related.
30 test runs per road type were conducted for the study. This means a total of approximately 6.000 km was driven on the test tracks. In the driving simulator similar measurements were taken as on the real roads (speed, lane keeping). Additionally the visual behaviour of the test drivers was captured.
The results of the tests in the driving simulator are being statistically analyzed in the same way as the results from the in situ measurements to guarantee comparability.

5.1 Driving simulator test sections

The driving optimized road sections were generated based on the suitable radii calculated using the software CARD/1. Therefore the circular curves with various radii and the associated clothoids and angles of aperture were strung together using a rational relation of radii. The average length of a driving optimized section is 5 kilometres. The sections can be connected indefinitely which allowed driving without discontinuation. Each subject had to drive on each test section driving a total of 20 km which allowed identifying random events.

Description	DC 4 real	DC 4 real nm	DC 4 nm
Alignment	Semi generous	generous	adapted
Radius range	R > 200 m	R > 200 m	150 m < R < 300m
Marking	Solid edge lines with single axis line	Broken edge lines (offset 0.75 m)	Broken edge lines (offset 0.75 m)
Traffic	With/without	With/without	With/without

Table 1: characteristics of the driving simulator sections

The real test sections were also generated with the software CARD/1 comparing the GPS data from the empirical studies and the existing data from the site plan. The length of those simulated sections varies depending on the present conditions. To obtain five kilometre long stretches additional elements were added to these sections. The low volume roads consisted of the characteristic elements shown in table 1. The different cross section design is displayed in figure 5.

5.2 Driving behaviour on low volume roads in the driving simulator

The analysis of the average speed behaviour of all test subjects (n=45 rounds) without other traffic resulted in the profiles shown in figure 6. The average speed in the before-situation was about 95.2 km/h. The after-situation had an average speed with a reduction by 5 % at about 91.3 km/h. An analysis by section for the open road and the junction area shows that the before-situation had an average speed of 105.0 km/h and 83.4 km/h. For the after-situation with the new single-lane cross-section for the open road section a reduced speed at about 99.9 km/h was noticed. For the junction area the average speed went up to about 86.3 km/h.

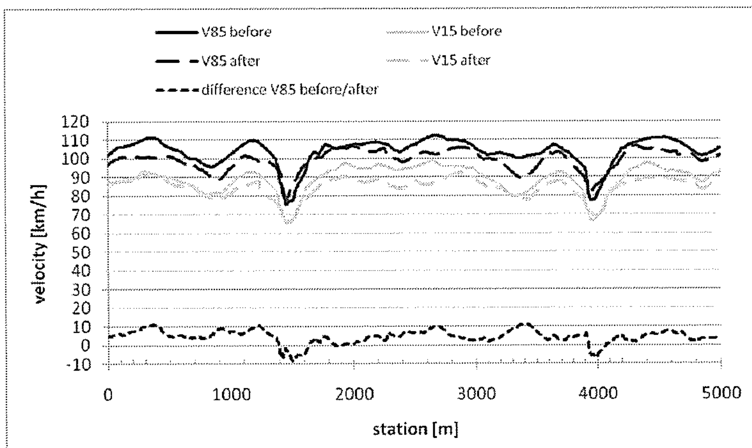


Fig. 6: speed profile for the real driving simulator sections with the old (RAS-Q) and new (RAL) marking

A precise consideration of the 85% speed shows likewise to the results on the test track a reduced speed in the open road section. Furthermore for the driving simulator section the speed reduction of

high speed levels decrease stronger than on lower speed levels. The converse progress can be noticed in junctions.
A high homogeneity of the speed profiles increases the safety level. The homogeneity itself can be displayed by several indicators. One of them is the frequency of the speed alterations over the stretch. The sum of the alteration for the before situation was 46.5 1/h. The after-situation had an alternation of the speed of 41.5 1/h. Therefore the speed over the stretch was more homogenous for the after-situation. On the other hand the homogeneity can be displayed by the variance of the drivers´ speed. Before the remarking the average variance was at 8.2 km/h. The after-situation had a lower average variance at 7.8 km/h. The 70%-canal which displays the difference of the V15 and the V85 (definition of the normal driver) did not show clear results.
Different to the test sections with the real alignment (generous alignment) the driving behaviour adjusted alignment (adapted alignment) resulted in lower driving speeds.

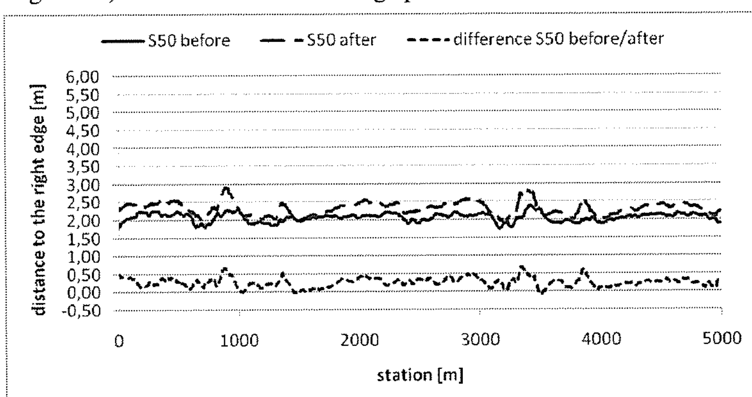


Fig. 7: average lane keeping without external traffic, difference lane keeping before/after

The lane keeping without traffic showed the results displayed in fig. 7. The comparison of the two kinds of markings showed similar to the real test track an offset to the right fin the after-situation. Fig. 7 proves as well that the average lane keeping differs by the alignment.

6 Conclusion

Overall the results of the project show that normalized road characteristics within design classes have positive effects on the driving behaviour and therefore the safety level on roads.
One major task is it to indicate the drivers on what road class they are driving on. Therefore the road markings are the essential elements to use. Especially on two lane cross-sections the different design standards were not indicated by the markings. By creating the new single lane cross-section the low volume roads are strictly separated from the standard roads.
The implementation of the new design classes will take several years and will bring along problems in the conversion. Therefore recommendations have to be given to the planners to ensure the correct effects [2]. Especially transition zones have to be dealt with cautiously.

7 References

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[3] RICHTER, Th. / ZIERKE, B. Sichere Gestaltung von Landstraßen durch normierte Streckencharakteristik (Safe design of rural roads by normalized road characteristics), DFG-Zwischenbericht, Berlin 2008, unveröffentlicht (unpublished)