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RELATIONSHIP BETWEEN HORIZONTAL CURVES DESIGN AND ACCIDENT RATE

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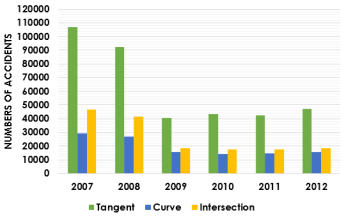
Graphical abstract



Abstract

Horizontal curves are very problematic elements of the road alignment. The danger of these spots is confirmed by the analysis of accidents, which showed that while on the tangents (straight sections) is an accident resulting in injury or death one of every five, at intersections and curve segments it is one of every three. Share of fatal accidents in curve segments compared to the intersections or direct segments is then more than doubled. The research aims to find potential correlations between different accident's characteristics and horizontal curves design, which could help predict dangerousness of horizontal elements. Strong correlation was proven between radius of horizontal curve and relative accidental rate. Lower correlation was found between traffic lanes width and relative accidental rate. From gathered data wasn't proven relationship between relative accidental rate and deflection angle.

Keywords: Horizontal curve, accident, radius, friction, superelevation

1.0 INTRODUCTION

With regards to accidents, horizontal curves are very problematic elements of roads. Key factors to determine instability of vehicle in curve are selection of driving speed and driving style. However not always can driver visually assess the horizontal curve well enough. This research aims to find the correlation between basic parameters of horizontal curves and different characteristics of accidents.

Minimal radius mentioned in technical standards is based on safety against side-slid. This principle is being used in Czech Republic and also in the most of other countries. Safety in horizontal curve is defined by following formula [1].

$$R \geq \frac{v^2}{127 * (f \pm 0{,}01 * p)}$$

R = curve radius (m); v = speed (km/h); f = friction (-); p = superelevation (%).

According to formula, it is obvious, that driving through horizontal curve is affected not only by selection of optimal speed, but also side friction factor and superelevation. While curve radius is usually recognizable visually, side friction or superelevation is not [2], [3].

2.0 ACCIDENT RATE IN HORIZONTAL CURVES

Every accident in Czech Republic is recorded with information about horizontal alignment in the location of accident. That's why it is possible to count number of accidents in curvy segments of roads and compare that with other segments. We recognize three main categories of road segments, tangents, curves and intersections. In category curves we distinguish two subcategories curves and tangent immediately following the curve.

Main cause of accidents in horizontal curve is speeding. In tangent sections immediately after horizontal curve is speeding cause of more than 59 %

of all accidents and responsible for more than 70 % fatal accidents. In curve segments is speeding cause of more than 53 % accidents and this cause is responsible for more than 64 % of fatal accidents [4].

Figure 1 showed a graph compares numbers of accidents located in Czech Republic with regards to horizontal alignment. Clearly the highest number of accidents is happening on tangent segments of roads (up to 55 %), the second most common places of accidents are intersections and last are horizontal curves with 20 % share of accidents. Big leap in graph between years 2008 and 2009 is caused by change of law in reporting accidents (with financial damage higher than 3 700 EUR).

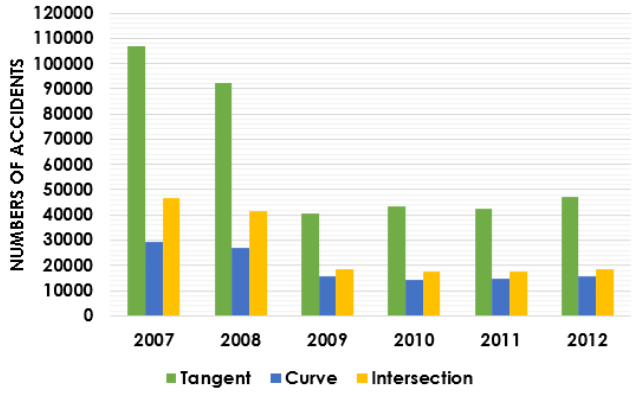


Figure 1 Numbers of accidents with regards to horizontal alignment

Despite that statistic comparing accidents ends in favor of horizontal curves, if we start taking into account only the accidents resulting in injury or death, accidents happening in horizontal curves are very on the top. While from all accidents happened in tangent segment every fifth results in injury or death, in intersection or curve segment it is every third (as showed in Figure 2. If we search for proportion of fatal accidents, we see that curve segments are even more dangerous. Proportion of fatal accidents in tangent or intersection segment is about 0.7 %, in curve segment it is about 1.6 %, more than two times higher [4].

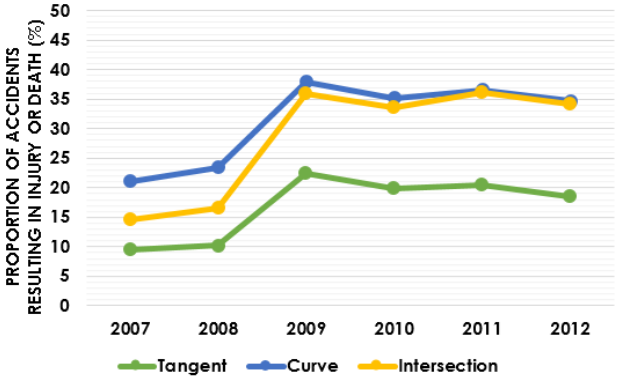


Figure 2 Proportion of accidents resulting in injury or death

3.0 THE METHODOLOGY

3.1 Selection of Horizontal Curves

Figure 3 and 4 showed a histogram of radius and deflection angle. Selection of horizontal curves was done by horizontal alignment analysis of I. class roads in South Moravian Region. Curves were selected according to maps, selected where those which are in rural areas and aren't significantly affected by other influences like intersections, speed limits, etc. 97 horizontal curves were selected for accident analysis. For each curve were determined basic parameters, like radius, deflection angle, width of traffic lanes and length of curve section.

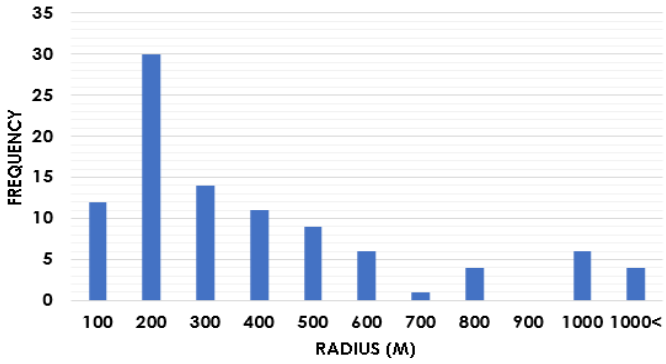


Figure 3 Histogram of radius

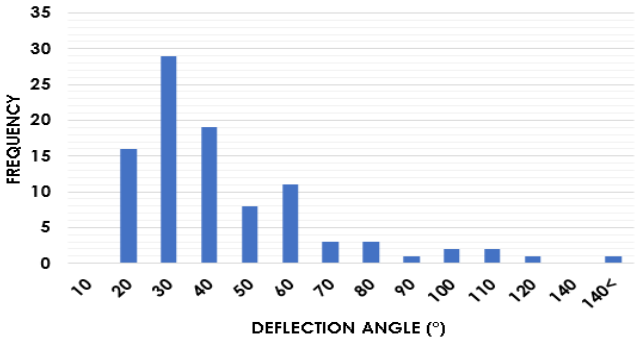


Figure 4 Histogram of deflection angle

From histogram it is obvious that frequency of radius and deflection angles is quite diverse. The smallest curve radius, which met required criteria for analysis, is 50 m and maximal is 3400 m. Minimal deflection angle is 11° and maximal is 142°.

3.2 Traffic Volume

Traffic volumes were determined for every analyzed segment of road (including selected horizontal curves), to compare accidental rates to traffic volumes. Not only total traffic volumes were considered, but also proportion of heavy vehicles were taken into account. Data about traffic volumes were gathered from National traffic census 2010.

3.3 Accident Rate

For every curve total number of accident was found. Only those which happened in curve segment were counted (or tangent segment immediately following curve segment). Included were also other parameters like number of fatal accidents, numbers of fatalities and injured people, surface conditions during accident and visibility.

For comparative analysis were selected standard indicator of relative accident rate, which included not only absolute number of accidents, but also traffic volume, duration or time period.

Indicator of relative accident rate is the most common used characteristic which indicates the probability of an accident on selected section of road in relation to traffic flow [5].

$$R \geq \frac{N_0}{365 * I * L * t} * 10^6$$

R = relative accident rate (number of accidents/ millions of vehiclekilometers per year); N_O = number of accidents; I = average daily traffic (vehicle/24h); L = length of section (km); t = monitored period of time (year).

3.0 RESULTS AND DISCUSSION

Table 1 showed a scle correlation coefficient. Based on inputs described above, analysis was performed to search for correlation between selected inputs. Nonlinear regression model and two main quality coefficients were used to find the relationship (correlation coefficient and coefficient of determination) [6].

Table 1 Scale correlation coefficient

Correlation coefficient	Strength of correlation
$\|R\| = 0$	None
$\|R\| < 0.2$	Weak
$0.2 \leq \|R\| \leq 0.4$	Low
$0.4 \leq \|R\| \leq 0.7$	Moderate
$0.7 \leq \|R\| \leq 0.9$	Strong
$0.9 \leq \|R\|$	Very strong
$\|R\| = 1$	Perfect

Coefficient of determination (R^2) tells how good the fit is, more precisely it tells what part (percentage) of inputs fit and what part doesn't. Correlation coefficient tells relationship between two random variables (R).

The most important correlation, which was proven on given inputs, is correlation between relative accident rate and curve radius. Relative accident rate includes both types of common accidents related to horizontal curves. Following figure showed in figure 5, that as radius of curve is lowering, relative accidental rate is raising. Correlation coefficient is 0.75, which indicates Strong correlation. Found exponential fits to 57 % inputs. It is necessary to note, that if we had considered only total number of accidents (without regards to traffic volume and length of curves), correlation coefficient would be 0.2, which indicates Weak correlation. So it is important to consider also the length of radius and traffic volume

If we consider only those accidents, which happened in curve segment, correlation coefficient would raise to 0.78 and coefficient of determination would raise to 61 %.

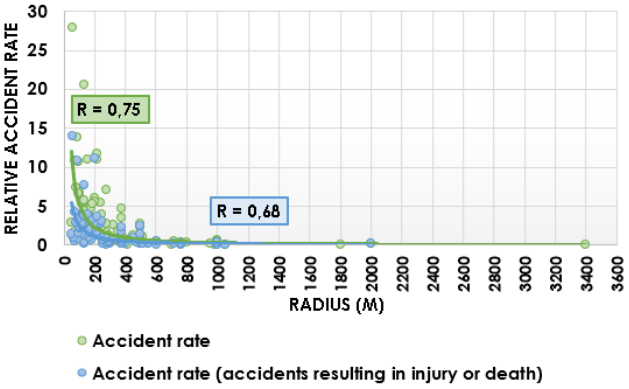


Figure 5 Relationship between relative accident rate and radius

Next correlation, which was analyzed, is correlation between curve radius and relative accident rate, which includes only accidents resulting in injury or death. Watched coefficients were lower than in previous case (where we considered all accidents). Correlation coefficient was lowered to 0.68, which indicates Moderate correlation and only 46 % of inputs fit to found relationship. It is necessary to note that seriousness of injury (or death) is not considered in relative accidental rate.

Because correlation was weakened, another relationship was analyzed. We compared relationship between curve radiuses and societal losses. Societal losses are financial losses (per person) which describe consequences of accidents resulting in injury or death. In 2013 [7] losses were quantified as follows:

- fatality = 716 000 EUR
- serious injury = 177 000 EUR
- light injury = 15 000 EUR

After determining societal losses for every horizontal curve, there was no correlation found. This result is supported by lowering correlation coefficient in previous relationship (radius vs relative accident rate) when only accidents resulting in injury or death were considered.

From gathered data correlation between relative accident rate and deflection angle (as you can see in following figure) was not found. Correlation coefficient indicates None to Weak correlation.

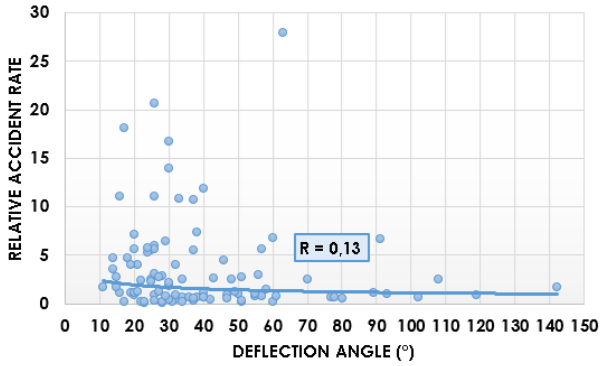


Figure 6 Relationship between relative accident rate and deflection angle

Similar unconvincing results were discovered in correlation between curve radius (or deflection angle) and number of accidents in unpleasant weather (fog, wet or icy carriageway). While there was no proven relationship between curve radius and different types of accidents, it is important to note, that accidents which happened during foggy conditions (or on wet carriageway) are important part of our input data. In both cases have these accidents over 50 % share in almost 1/3 of horizontal curves as shown in Figure 6.

In Figure 7, moderate correlation was found in relationship between width of traffic lanes and relative accident rate. Correlation coefficient is 0.48 and found relationship fits to over 23 % of gathered data. It is necessary to note that in many cases traffic lanes were not widened according to technical standard.

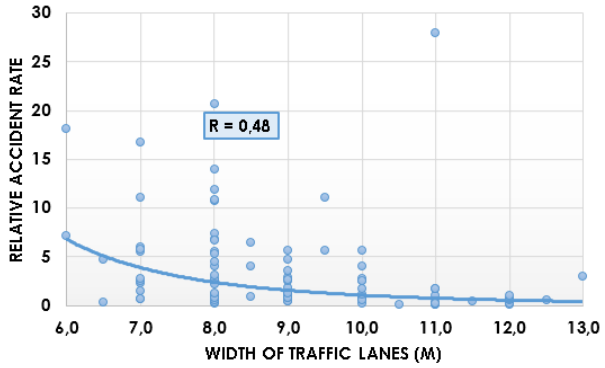


Figure 7 Relationship between relative accident rate and width of traffic lanes

4.0 CONCLUSION

According to general analysis of accident rate in horizontal curves in Czech Republic was proven that even though accidents in horizontal curves happens less often, they are more dangerous with regards to their consequences. While every fifth accident which happens in tangent results in injury or death, in intersections and curves is the risk almost two times higher (every third accident results in injury or death). If we count only fatalities, risk in intersections and curves is two times more probable, than in other places of accidents.

During comprehensive analysis of accidental rate were examined 97 horizontal curves, for each were identified relevant parameters. Analysis proved strong correlation between relative accident rate and curve radius. However strong correlation was proven only with section length and traffic volume consideration, without these parameters is correlation weak. Quite significant lowering of correlation coefficient was found when curve radius is over 250 m.

Relationship between deflection angle and relative accident rate or relationship between curve characteristics and seriousness of accident consequences weren't proved with analyzed data. Also relationship between accidents, which happened during lower visibility or during wet surface, and deflection angle and radius wasn't proved. Moderate correlation was found between width of traffic lanes and relative accident rate.

Acknowledgement

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