THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2010

5(3): 177–184

PHD THESIS

# POSSIBILITIES FOR THE IMPROVEMENT OF THE QUALITY OF DESIGN SOLUTIONS IN THE GRAVEL ROAD RECONSTRUCTION PROJECTS

**Vilimas Gintalas**

*Technological Science, Civil Engineering 02T*
*Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania*
*E-mail: vilimas.gintalas@vgtu.lt*

**Abstract.** This summary of the author's PhD thesis supervised by Prof Dr Donatas Čygas and defended on 25 February 2010 at the Vilnius Gediminas Technical University. The thesis is written in Lithuanian and is available from the author upon request. Chapter 1 gives analysis of Gravel Road Network and analysis of gravel roads Development in the Republic of Lithuania. Chapter 2 gives analysis of the road design standards of the Republic of Lithuania and foreign countries. Chapter 3 gives methodology of experimental investigations. Chapter 4 gives results of experimental investigations. Chapter 5 gives generalization of investigation results.

**Keywords:** gravel road, road alignment, geometrical parameters, horizontals curves, design solution.

## State of the problem

Despite large investments in the development of the road network of national significance and the improvement of traffic safety, the number of accidents on the roads of the Republic of Lithuania in the last years remained one of the largest in the European Union (EU). This allows to make an assumption that not all the improvements of the road network are sufficiently effective, including design solutions of the road reconstruction projects. A great concern is caused by the design solutions in the gravel road reconstruction projects which could be unsuitable in terms of traffic safety, since it is common practice in Lithuania to design the planned road axis of the gravel road to be reconstructed with the min deviation from the existing road axis. The main motivation for this gravel road reconstruction practice is to reduce the cost of reconstruction works at the expense of taking of land for the planned right-of-way. Another important reason for making the currently used practice of the reconstruction of lower-category roads, including gravel roads, is the liberal road design standards of the Republic of Lithuania allowing to rather freely interpreting observance of their requirements.

**Topicality of the work.** Motivation for the gravel road reconstruction practice used in Lithuania in the last 10 years can possibly be insufficiently justified. Besides, in the road design standards of the Republic of Lithuania the main requirements for the solutions of road alignment had been essentially changing, therefore, the current design standards can contain certain inaccuracies which must be corrected. Also, it is necessary to supplement the road design standards with the new requirements ensuring the solutions of a smooth and safe road alignment.

**The object of research** – regularities for the design of road alignment, design solutions in the gravel road reconstruction projects and their links with the requirements of road design standards.

**Aim and tasks of the work.** The aim of this work – to determine regularities for the design of road alignment, their links with the requirements of road design standards and to suggest the methods for improving the quality of design solutions.

The following tasks were solved to achieve the aim of the work:

- to make analysis of the requirements of road design standards regulating the solutions of road alignment and to give suggestions for the improvement of these regulations;
- to evaluate the quality of the existing road alignment and the volume of possible correction of horizontal and vertical alignment of the gravel road sections to be reconstructed;
- to carry out investigations of accident rate of the reconstructed gravel road sections by comparing the accident rate before and after reconstruction;

ISSN 1822-427X print / ISSN 1822-4288 online doi: 10.3846/bjrbe.2010.25

http://www.bjrbe.vgtu.lt

– to determine the quality of design solutions of road alignment in the gravel road reconstruction projects;
– to identify the volume of taking of land for the right-of-way in case if the gravel road reconstruction projects had been prepared according to the requirements of design standards;
– to evaluate if the current practice in Lithuania when reconstructing gravel roads to use the least deviation from the existing road axis is justified.

**Methodology of research.** In order to determine possible inaccuracies in the requirements of road design standards of the Republic of Lithuania regulating the solutions of road alignment and to give suggestions for correcting and supplementing these requirements the method of comparative analysis was used for the investigations of this work. 3 experimental investigations were carried out using methodology developed during the preparation of this work, i.e.:

– for the investigation of horizontal alignment of gravel roads;
– for the investigation of vertical alignment of gravel roads;
– for the prediction of the volume of taking of land for public needs.

Statistical methods were used for the investigations of the accident rate of gravel roads before and after reconstruction. For experimental investigations to define the quality of design solutions in the gravel road reconstruction projects the methodology of traffic safety criteria was applied.

**Scientific novelty.** The following results new to the science of civil engineering were obtained in the course of preparation of the dissertation:

– a new design methodology adjusted to the improvement of requirements of road design standards regulating the solutions of road alignment and to the improvement of the quality of design solutions in the road reconstruction projects, intended for studying road alignment as a succession of interrelated elements;
– geometrical parameters of the existing alignment of gravel roads in the road network of national significance of the Republic of Lithuania;
– determination of the quality of design solutions of road alignment in the gravel road reconstruction projects;
– changes in the accident rate of gravel roads before and after reconstruction.

**Practical value.** The practical application of the results of investigations carried out within the framework of this work would enable to improve the quality of design solutions when preparing reconstruction projects for the lower-category rural roads:

– road design standards of the Republic of Lithuania would be improved and would ensure design solutions for a geometrically smooth and safe road alignment;
– the use of methodology of traffic safety criteria would enable to identify and eliminate the potentially dangerous road sections early in the stage of their design.

**Defended propositions.** It is necessary to improve the requirements of road design standards of the Republic of Lithuania based on regularities for the design of road alignment and the quality of design solutions in the road reconstruction projects.

When preparing the gravel road reconstruction projects a possibility of deviation from the existing road axis shall not be restricted.

## Gravel road network and its development in the Republic of Lithuania and analysis of its development

A large part of the road network of national significance of Lithuania is still made of gravel roads. In 1998 the Gravel Roads Paving Programme (hereafter Programme) was started to be implemented the main objectives of which is to increase the density of road network with the improved pavement and to eliminate the current disproportions in the development of road network. According a data of the Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania during implementation of the Programme in 1998–2009 the part of gravel roads in the road network of national significance was decreased from 49.1% to 35.9%, and until the year 2015 it is aimed to decrease this part to 30%.

However, the practice of implementing the Programme revealed serious deficiencies, the most important of which – hastiness in the programme implementation having the aim that the period from the beginning of design works to the end of reconstruction works would last no more than 1–2 years. Such a short period of time is possible in those cases when the alignment of the existing gravel road is not being corrected or the correction of alignment is restricted by the requirement that the planned roadbed would go into the existing right-of-way. Such design solutions of road alignment are supposed to be acceptable in the gravel road reconstruction projects and this became a common practice of implementing the Programme. This practice of laying the improved pavement on gravel roads is not applied in the neighbouring Baltic countries.

The reasoning and consequences of the current practice of implementing the Programme has not been objectively determined yet. Since accident indices in Lithuania remain one of the worst in the EU the assurance of road traffic safety is one of the most important tasks of present-day. Therefore, it is very important to avoid the worsening of traffic conditions in the reconstructed gravel roads.

## Analysis of the road design standards of the Republic of Lithuania and foreign countries

The aim of investigation – to compare the requirements of road design standards regulating the solutions of road alignment of various countries, to determine possible inaccuracies in the design standards of the Republic of Lithuania and to give recommendations for the correction of inaccuracies determined and for the improvement of design standards (Gintalas *et. al.* 2005).

It was determined during the comparison of requirements of road design standards of the Republic of Lithuania and other countries that some requirements for the solutions of road alignment in Lithuania are significantly different from the analogical requirements in the design standards of other countries:

– only two speeds are determined for design needs – design speed $V_d$ and permissible speed $V_p$;
– there is no concept of the speed $V_{85}$ characterizing a real driving speed of vehicles;
– no indication is given on the methodology based on which the $V_d$ is determined;
– the min radii of horizontal and vertical curves are obviously different from the average used in other countries.

The min radii of horizontal curves defined in the current road design standards of the Republic of Lithuania are higher than those defined in the standards of other countries, whereas, the radii of humps are apparently lower. The least deviation from the average of foreign countries is represented by the radii of transverse depressions. Therefore, there are some doubts if the radii of horizontal and vertical curves in the current road design standards of the Republic of Lithuania are properly justified (Gintalas *et. al.* 2007a).

The radii of horizontal and vertical curves were checked by the formulas presented in the literature sources, making an assumption that pavement properties in Lithuania correspond to the average of West European countries and USA – the values of tangential friction factor $f_T$ and side friction factor $f_R$ used in the formulas were calculated by overall regression equations that were made during the investigations carried out in the above mentioned countries (Бабков *et al.* 1970; Бабков 1983; Кудрявцев *et al.* 1973; Хавкин *et al.* 1966; Lamm 1984; Lamm *et al.* 1989; Lamm *et al.* 1990b; Lamm *et al.* 1992; Lamm *et al.* 1995a; Lamm 1995c; Lamm *et al.* 1996).

It was determined that in the road design standards of the Republic of Lithuania:

– the values of the radii of horizontal curves are set with a large reserve, and this reserve is unjustified;
– the values of the radii of vertical curves are inconsistent with the visibility requirements and, in contrast to the horizontal curves, are too low or having no reserve.

When preparing road construction or reconstruction projects it is very important to not only properly design separate elements of road alignment but also to properly combine them in-between. In order to ensure the solutions of smooth and sage road alignment the following requirements are given in the road design standards:

– for the compatibility of the radii of adjacent horizontal curves;
– for the compatibility of the radii of horizontal curves and the lengths of tangents between the curves;
– for a geometrical smoothness of the whole road alignment.

To properly select the radii of adjacent horizontal curves usually the detail nomograms of radii compatibility are presented which are almost the same in the road design standards of various countries. Requirements for the compatibility of the radii of horizontal curves and the lengths of tangents between the curves are usually not so comprehensive as for the compatibility of the radii of adjacent horizontal curves, and this is a certain deficiency of design standards. Another deficiency of the road design standards of the Republic of Lithuania is that the smoothness of the whole road alignment is only mentioned and no recommendations are given on how to achieve it.

This work describes a new road design methodology according to which road alignment is studded as a sequence of successive interrelated elements. This methodology is based on the concepts of Curvature Change Rate ($CCR_S$) and traffic safety criteria (Lamm *et al.* 2007; Lamm *et al.* 1971b; Lamm *et al.* 1990b; Thoma 1994).

The traffic safety criteria are as follows:

– criterion I – stability of the $V_d$;
– criterion II – stability of the $V_{85;}$
– criterion III – dynamic stability on horizontal curves.

Having summed up the values of traffic safety criteria and having calculated their average, the design level of traffic safety module is identified (Gintalas *et. al.* 2008).

Methodology based on the traffic safety criteria allows us:

– to properly select the $V_d$ according to the calculated values of $V_{85}$ for the whole road section to be reconstructed or for its separate segments;
– to properly combine between each other the elements of road – horizontal curves and tangents between them.

Using this methodology the problem of modelling the $V_{85}$ in horizontal curves and the tangent between them was solved in this work (Fig. 1), the aim of which – to give detail recommendations for the compatibility of the elements of horizontal alignment (Lamm *et al.* 1993b; Lamm *et al.* 1995a; Lamm *et al.* 1995b).

Problem formulation – to find out the max tangent length *TL* when the following is given:

– the radii of horizontal curves $R_1$, $R_2$;
– the permissible difference $\Delta V_{85}$ between the $V_{85}$ in horizontal curves and the tangent.

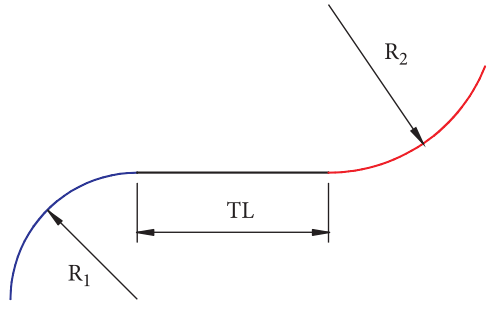


**Fig. 1.** The scheme for solving the problem of compatibility between the elements of horizontal alignment

Problem solution:

– speed in horizontal curves

$$V85_i = 105.31 + 2 \times 10^{-5} \times CCR_{S_i}^2 - 0.071 \times CCR_{S_i}, \quad (1)$$

where $CCR_{S_i}$ – the curvature change rate in curve *i*;

– speed in tangent

$$V85_T = \min\begin{pmatrix} \min(V85_1, V85_2) + \Delta V_{85} \\ 105.31 \end{pmatrix}; \quad (2)$$

– tangent length

$$TL = \frac{2 \times V85_T^2 - V85_1^2 - V85_2^2}{22.03}. \quad (3)$$

By joining (1)–(3) formulas together the final expression of tangent length is obtained

$$TL = \min\left(\begin{matrix} 105.31 + 2 \times 10^{-5} \times \left(\frac{63700}{\min(R_1, R_2)}\right)^2 - 0.071 \times \frac{63700}{\min(R_1, R_2)} + \Delta V_{85} \\ 105.31 \end{matrix}\right) -$$
$$-1006.8 - \frac{2.9895 \times 10^8}{R_1^4} + \frac{3.3321 \times 10^7}{R_1^3} - \frac{1.7044 \times 10^6}{R_1^2} + \frac{43240}{R_1} - \quad (4)$$
$$-1006.8 - \frac{2.9895 \times 10^8}{R_2^4} + \frac{3.3321 \times 10^7}{R_2^3} - \frac{1.7044 \times 10^6}{R_2^2} + \frac{43240}{R_2}.$$

The tables of recommended max tangents between the small-radius (100–500 m) horizontal curves were worked out based on (4) formula.

**Methodology of experimental investigations**

The chapter describes methodology developed or adjusted during the preparation of this work for the following experimental investigations:

– for the investigation of horizontal alignment of gravel roads;
– for the investigation of vertical alignment of gravel roads;
– for the investigation of accident rate of gravel roads;
– for the determination of the quality of design solutions in the gravel road reconstruction projects;
– for the prediction of taking of land for the right-of-way.

Investigation of horizontal alignment was carried out in the following stages (Gintalas *et al.* 2005b; Gintalas *et al.* 2007a; Gintalas *et al.* 2007b; Gintalas *et al.* 2008; Vitkienė *et al.* 2008):

– vectorization of road alignment in the digital orto-photographical map ORT10;
– separation of a linear object, representing the road axis, into the tangents and circular arcs, determination of the position of turning points (vertices of the angles) of road alignment and identification of coordinates;
– drawing-up and analysis of the lists of turning angles, tangents and curves.

Investigation of vertical alignment of gravel roads was carried out in the following stages:

– measurements of vertical alignment by the GPS (Global Positioning System) receiver;
– modeling of the existing vertical alignment with the tools of computer-aided design (CAD) system;
– drawing-up and analysis of the lists of elements of vertical alignment.

Using the tools of computer-aided design system the modelling of the existing vertical alignment was carried out in the following order:

– development of a digital model of location;
– design of horizontal alignment without deviation from the existing axis;
– design of vertical alignment without deviation from the existing heights.

The main objective of the investigation of accident rate of gravel roads is to compare accident indices on the reconstructed gravel road sections before and after their reconstruction (Elvik 2009; Gintalas *et al.* 2008; Hauer 2005; Kapski *et al.* 2007, 2008; Peltola 2000; Ratkevičiūtė *et al.* 2006; 2008).

Investigation of accident rate of gravel roads was carried out in the following stages:

– collection of accident data on the reconstructed gravel road sections;
– comparison of accident indices before and after reconstruction;
– economic evaluation of accident losses.

For the analysis of the quality of design solutions in the gravel road reconstruction projects the following investigations were implemented:

– evaluation of the correspondence of the solutions of horizontal alignment to the requirements of design standards;
– identification of potentially dangerous road segments based on the methodology of traffic safety criteria.

The aim of evaluating the correspondence of the solutions of horizontal alignment to the requirements of design standards was to determine what part of horizontal curves is designed improperly. The following horizontal curves were attributed to the improperly designed ones:

– curves the radii of which are lower that it is required by the design standards valid at the time of project preparation;
– curves with the improperly designed transition curves.

When identifying potentially dangerous segments that may appear in the implemented gravel road reconstruction projects each section under investigation was divided into segments in a way that one segment correspond to one element of horizontal alignment. Investigation was carried out in the following stages:

– identification of dangerous segments on the sections under investigation;
– collection of accident data on the sections under investigation;
– determination of statistical relationship between the accidents on the sections under investigation and the identified dangerous segments on them.

Identification of dangerous segments on the road sections under investigation was carried out in the following order:

– determination of the average $CCR_S$;
– determination of the speed $V_{85}$ using the overall world-wide regression equations;
– analysis of the planned road alignment by defining for each segment a design level of traffic safety module;
– identification of a dangerous road segment if the value of a dangerous design level of traffic safety module is obtained;
– dangerous segments were identified for both traffic directions.

When reconstructing roads the following situations may occur:

– correction of horizontal alignment (position of the road axis is changed);
– increase in the width of right-of-way.

In both cases the taking of land for the right-of-way is necessary by the established order of the Law on Territorial Planning.

The objectives of predicting the volume of taking of land for the right-of-way are as follows:

– to determine the volume of possible taking of land for the right-of-way in case when the detail designs for the gravel road reconstruction are prepared according to the requirements of design standards;
– to determine possible costs of taking of land and their ratio to the cost of road reconstruction works.

Investigation of the volume of possible taking of land for the right-of-way was implemented in the following stages:

– design of one of the possible alternatives for the planned road alignment with the tools of computer-aided design system;
– determination of land areas to be taken for the right-of-way according to the deviation of the planned road axis in respect of the existing road axis;
– identification of the number of land plots the limits of which have to be corrected due to the deviation of the road axis based on the database of SE Registrų centras (Centre of Registers);
– determination of possible costs of taking of land for the right-of-way;
– analysis of results.

**Results of experimental investigations**

Investigations of horizontal and vertical alignment were carried out on the planned to be reconstructed gravel roads under the supervision of SE Telšių regiono keliai. Investigations of horizontal alignment were implemented on 24 sections with the total length of 111.90 km. Investigations of vertical alignment of gravel roads were carried out on 21 road section with the total length of 95.50 km. Investigation results showed that the quality of the existing road alignment of gravel roads is poor – 56–78% of horizontal curves (making 19–27% of the length of investigated sections) and 68–89% of vertical curves (making 25–36% of the length of investigated sections) should be corrected (Fig. 2).

Investigation of accident rate was implemented on 53 reconstructed gravel road sections in the Western Lithuania, the total length of which – 204.88 km. On those sections in the period 1998–2006 199 fatal and injury accidents were recorded, 76 of which – before reconstruction, 123 – after reconstruction. Besides, after reconstruction 2 high-accident sections and 2 black spots were recorded on the gravel roads under investigation. Investigation results showed that:

– after reconstruction the average density of fatal and injury accidents on the sections of investigation sample has increased twice – from 0.06 to 0.13 accidents per year;
– accident costs per 1 km of the reconstructed gravel road, in the investigated sections were about 93 000 Lt/year (based on 2006 prices).

A more comprehensive analysis of accident rate was carried out on the gravel roads under the supervision of SE Telšių regiono keliai by analyzing both types of accidents – fatal and injury as well as damage-only accidents (Fig. 3). It was determined that after reconstruction of the gravel roads under the supervision of SE Telšių regiono keliai the density of both types of accidents has increased 2.7 times.

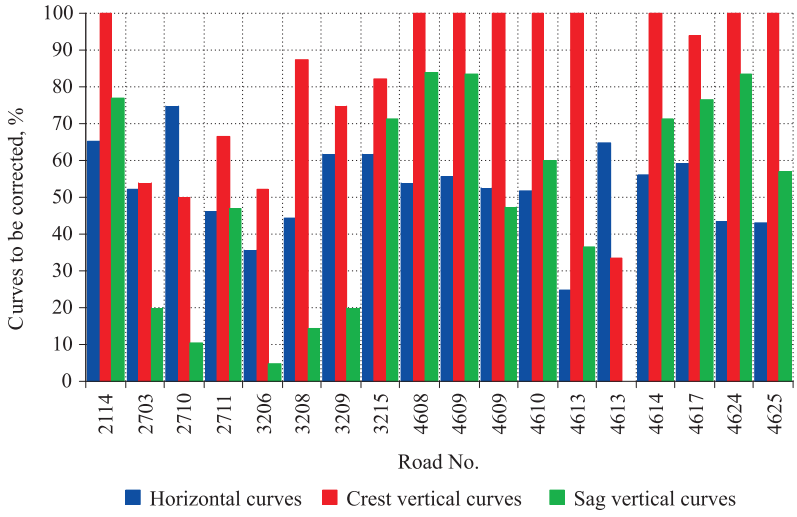


**Fig. 2.** Distribution of horizontal and vertical curves to be corrected when $V_d$ = 70 km/h

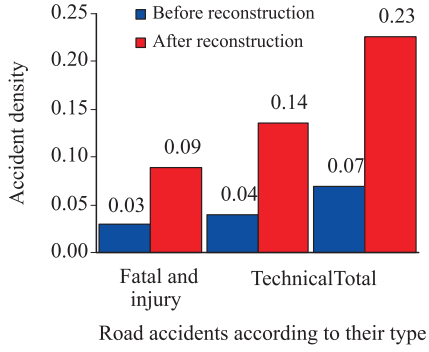


**Fig. 3.** Comparison of accident density of each type of accidents before and after reconstruction of gravel roads under the supervision of SE Telšių regiono keliai

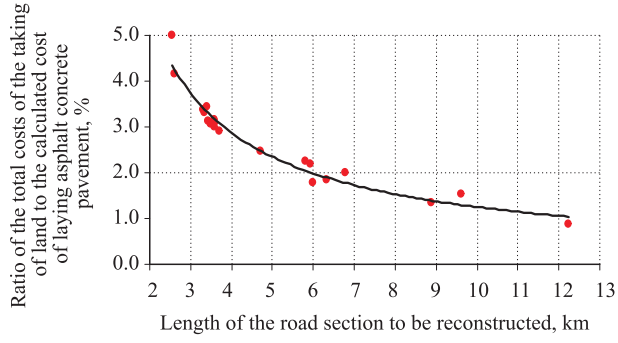


**Fig. 4.** Dependency of the ratio between the total costs of taking of land for the right-of-way and the calculated cost of laying asphalt concrete pavement on the length of the road section to be reconstructed

Evaluation of the correspondence of the solutions of horizontal alignment to the requirements of design standards was carried out on the sections of the accident rate investigation sample – 53 detail designs of gravel road reconstruction, prepared for the road sections with the total length of 204.88 km, were studied. It was determined that 14 gravel road reconstruction projects (26.4% of all the projects) were prepared without giving any solutions for the horizontal alignment. 39 gravel road reconstruction projects (73.6% of all the projects) were fully completed, however, the quality of the solutions of horizontal alignment was poor – on the average 34.9% of horizontal curves were designed improperly.

Investigation for identifying the potentially dangerous segments was implemented on 8 gravel road sections with the total length of 39.26 km. For this investigation the detail designs of gravel road reconstruction were also used. It was determined that at least 5% of the total length of investigated reconstructed gravel road sections is made of the potentially dangerous segments, besides, there is a statistical correlation between the identified dangerous road segments and the accidents on them. When identifying the potentially dangerous segments it was also determined that in all detail designs of investigation sample the $V_d$ was selected improperly – based on the design standards, valid at the time of their preparation, the value of $V_d$ = 60 km/h was set, whereas, it had to be set as $V_d$ = 70–90 km/h.

The forecast of the volume of taking of land for the right-of-way shows that:

- when taking land for the right-of-way the predicted costs per one gravel road section to be reconstructed average to 59 000 Lt of the calculated cost of laying asphalt pavement;
- the higher the length of the section to be reconstructed the lower ratio would be between the costs of taking of land for the right-of-way and the calculated cost of laying asphalt pavement (Fig. 4).

It was determined that the ratio between the costs of taking of land for the right-of-way and the calculated cost of laying asphalt pavement is also related to the length

of the section to be reconstructed in a dependency which could be described by an exponential function:

$$S = m \times L^n, \quad (5)$$

where $S$ – ratio between the total costs of taking of land for the right-of-way and the calculated cost of laying asphalt concrete pavement, %; $L$ – length of the road section to be reconstructed, km; $m$, $n$ – coefficients of exponential function.

**Generalization of investigation results**

This chapter gives an overview of results of all investigations carried out during the preparation of this dissertation:

- detail recommendations for improving the road design standards of the Republic of Lithuania regulating the solutions of road alignment;
- results of all experimental investigations implemented.

**General conclusions**

When analyzing regularities of the design solutions of road alignment and their links with the regulations of road design standards it was determined that the current regulations of road design standards of the Republic of Lithuania have certain inaccuracies and deficiencies. A further use of these requirements for designing road alignment will result in the preparation of low-quality road reconstruction projects in terms of traffic safety, especially on the roads of lower categories.

Investigations of horizontal and vertical alignment of gravel roads show that the quality of the existing alignment of gravel roads is poor – 56–78% of horizontal curves and 68–87% of vertical curves should be corrected.

In the result of comparative investigations of accident rate of the reconstructed road sections it was determined that:

- after reconstruction the accident rate (accident density) is increased up to 3 times;
- accident costs per 1 km of the reconstructed gravel road make about 93 000 Lt/year (based on 2006 prices).

Based on the analysis of the quality of design solutions in the gravel road reconstruction projects, it could be stated that:

- the values of design speed $V_d$ are selected improperly;
- requirements for the solutions of horizontal alignment of roads are not observed – approximately one third of horizontal curves are designed incorrectly;
- the elements of horizontal alignment are incompatible – at least 5% of the total length of the reconstructed road sections are comprised of potentially dangerous segments.

When taking land for the right-of-way the predicted expenditures per one gravel road section to be reconstructed are averaged to 59 000 Lt (based on 2006 prices). They make only a small part of the calculated cost of road reconstruction works, and this part has been notably decreasing with the increasing length of the road section to be reconstructed. Therefore, it is recommended to reconstruct gravel roads in the longest possible sections.

Annual losses caused by the road accidents on improperly reconstructed gravel road sections are larger than onetime expenditures for taking of land for the planned right-of-way. Therefore, it could be stated that the current practice in Lithuania to design the min possible deviation of the design road axis from the existing road axis is not reasonable from the technical and economic point of view.

The recommended corrections and supplements to the requirements of road design standards of the Republic of Lithuania are as follows:

- to replace the min radii of horizontal and vertical curves with the radii values suggested in this work;
- to present the revised recommendations, suggested in this work, for the compatibility of horizontal curve radii and the lengths of tangents between the curves;
- to supplement design standards with the concepts of $85^{th}$-percentile speed ($V_{85}$), the Curvature Change Rate ($CCR_S$), traffic safety criteria, traffic safety modulus and its design levels;
- to change requirements for the determination of $V_d$ – to specify that the value of $V_d$ shall be justified by the calculations.

**References**

Elvik, R. 2009. An Exploratory Analysis of Models for Estimating the Combined Effects of Road Safety Measures, *Accident Analysis & Prevention* 41(4): 876–880. doi:10.1016/j.aap.2009.05.003

Gintalas, V.; Čygas, D.; Žilionienė, D.; Puodžiukas, V. 2005b. Problems of Road Plan Designing when Implementing Paving of Gravel Roads Program in Lithuania, in *Proc of the 6th International Conference "Environmental Engineering": selected papers,* vol. 3. Ed. by Čygas, D.; Froehner, K. D. May 26–27, 2005, Vilnius. Vilnius: Technika, 691–694.

Gintalas, V.; Čygas, D.; Žilionienė, D.; Puodžiukas, V. 2007a. Longitudinal Profile of the Objects Included in the Gravel Roads Paving Program of Lithuania, *The Baltic Journal of Road and Bridge Engineering* 2(2): 53–59.

Gintalas, V.; Čygas, D.; Žilionienė, D.; Puodžiukas, V.; Lašinytė, A. 2007b. Research and Evaluation of the Effect of Taking the Land for Public Needs on the Cost of Gravel Road Reconstruction, *The Baltic Journal of Road and Bridge Engineering* 2(4): 165–171.

Gintalas, V.; Žilionienė, D.; Čygas, D.; Juzėnas, A. 2005a. Design of Lithuanian Rural Highways from the Aspect of Sustainable Road Network Development, in *Proc of the 3rd International Symposium on Highway Geometric Design*, June 29–July 1, 2005, Chicago – USA, 18 p. Compendium of papers CD-ROM.

Gintalas, V.; Žilionienė, D.; Dimaitis, M.; Lukošaitis, T.; Lipnevičiūtė, K.; Vitkienė, J. 2008. Analysis of Design Solutions in the Objects of Gravel roads Paving Program in Terms of Traffic Safety, *The Baltic Journal of Road and Bridge Engineering* 3(2): 93–100. doi:10.3846/1822-427X.2008.3.93-100

Hauer, E. 2005. *Observational Before-After Studies in Road Safety. Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety.* Dept of Civil Engineering, University of Toronto. Canada. 289 p.

Kapski, D.; Leonovich, I.; Ratkevičiūtė, K. 2007. Theoretical Principles of Forecasting Accident Rate on the Conflict Sections of the Cities by the Method of Potential Danger, *The Baltic Journal of Road and Bridge Engineering* 2(3): 133–140.

Kapski, D.; Leonovich, I.; Ratkevičiūtė, K.; Miškinis, D. 2008. Implementation of Experimental Research in Road Traffic: Theory and Practice, *The Baltic Journal of Road and Bridge Engineering* 3(2): 101–108. doi:10.3846/1822-427X.2008.3.101-108

Lamm, R. 1984. Driving Dynamics Considerations: A Comparison of German and American Friction Coefficients Highway Design, *Transportation Research Record* 960: 13–20.

Lamm, R. 1995c. Highway Geometric Design with Special Emphasis on Traffic Safety-Based on International Research and the New Greek Guidelines for the Design of Highway Facilities, Part: Alignment, in *Proc of the 1st Greek Congress of Highway Engineering*, October 4–7, 1995. Larisa.

Lamm, R.; Beck, A.; Rusher, T.; Mailaender, T. 2007. *How to Make Two-Lane Rural Roads Safer*. Southampton, Boston.

Lamm, R.; Choueiri, E. M.; Goyal, P. B.; Mailaender, T. 1989. An Attempt to Develop Reliable Friction Factors vs. Speed for Design Purposes. A Case Study Based on Actual Pavement Friction Inventories, in *Proc of the Forty-Third Annual Ohio Transportation Engineering Conference*, Ohio, 168–189.

Lamm, R.; Choueiri, E. M.; Mailaender, T. 1990b. Comparison of Operating Speeds on Dry and Wet Pavements of Two-Lane Rural Highways, *Transportation Research Record* 1280: 199–207.

Lamm, R.; Choueiri, E. M.; Psarianos, B.; Soilemezoglou, G. 1995a. A Practical Safety Approach to Highway Geometric Design, International Case Studies: Germany, Greece, Lebanon, and the USA, in *International Symposium on Highway Geometric Design Practices, Transportation Research Board,* Boston.

Lamm, R.; Mailaender, T.; Steffen, H.; Choueiri, E. M. 1992. Side Friction in International Road Design and Possible Impacts of Traffic Safety, *Road and Construction* 5: 6–25.

Lamm, R.; Mailaender, T.; Steffen, H.; Choueiri, E. M. 1993. Safety Evaluation Process for Modern Highway Geometric Design on Two-Lane Rural Roads, in *Research Report V for CTI Engineering Co. Ltd*., Tokyo; Karlsruhe.

Lamm, R.; Psarianos, B.; Drymatlitou, D.; Soilemezoglou, G. 1995b. *Guidelines for the Design of Highway Facilities,* vol. 3. Athens.

Lamm, R.; Psarianos, B.; Soilemezoglou, G.; Kanellaidis, G. 1996. Driving Dynamic Aspects and Related Safety Issues for Modern Geometric Design of Non Built-Up Roads, *Transportation Research Record* 1523: 34–45. doi:10.3141/1523-05

Lamm, R.; Schlichter, H. G. 1971b. Driving Behavior under Different Weather and Daylight Conditions, *Road and Construction* 12: 873–877.

Peltola, H. 2000. Background and Principles of the Finnish Safety Evaluation Tool, TARVA, in *Proc of the 13th ICTCT workshop, Evaluation of Traffic Safety Measures*. Corfu, Greece, 67–79.

Ratkevičiūtė, K.; Čygas, D.; Bernotaitė, I. 2008. Analysis of Methodologies for the Evaluation of Effects of Road Safety Measures, in *Proc of the 7th International Conference "Environmental Engineering": selected papers*, vol. 3. Ed. by Čygas, D.; Froehner, K. D. May 22–23, 2008, Vilnius, Lithuania. Vilnius: Technika, 1214–1222.

Ratkevičiūtė, K.; Čygas, D.; Laurinavičius, A. 2006a. The Methodology of Selection Traffic Safety Improvement Measures in Lithuanian Road Network, in *Proc of the 4th International Conference "On Safe Roads in the XXI. Century"*. 25–27 October, 2006, Budapest, Hungary, 1–6.

Ratkevičiūtė, K.; Čygas, D.; Laurinavičius, A.; Mačiulis, A. 2007. Analysis and Evaluation of the Efficiency of Road Safety Measures Implemented on Lithuanian Roads, *The Baltic Journal of Road and Bridge Engineering* 2(2): 81–87.

Thoma, J. 1994. Speed Behavior and Risks for Different Road Conditions, Weekdays and Daytimes, *Technical Journals for Traffic Safety* 1: 7–11.

Vitkienė, J.; Puodžiukas, V.; Žilionienė, D.; Gintalas, V. 2008. Analysis of the computer aided design models for roads, in *Proc of the 7th International Conference "Environmental Engineering": selected papers,* vol. 3. Ed. by Čygas, D.; Froehner, K. D. May 22–23, 2008, Vilnius, Lithuania. Vilnius: Technika, 1242–1246.

Бабков, В. Ф. 1983. *Автомобильные дороги*. Москва: Транспорт. 280 с.

Бабков, В. Ф.; Андреев, О. В.; Замахаев, М. С. 1970. *Проектирование автомобильных дорог.* Москва: Транспорт. 400 с.

Кудрявцев, М. Н.; Каганович, В. Е. 1973. *Изыскания и проектирование автомобильных дорог.* Москва: Транспорт. 398 с.

Хавкин, К. А.; Дашевский, Л. Н. 1966. *Проектирование продольного профиля автомобильных дорог.* Москва: Транспорт. 237 с.

*Recieved 01 March 2010; accepted 02 June 2010*