



PHD THESIS

ASSURANCE OF THE FUNCTION OF LOW-VOLUME ROADS
FOR THE IMPROVEMENT OF DRIVING CONDITIONS

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Abstract. This summary of the author's PhD thesis supervised by Assoc Prof Dr Daiva Žilionienė and defended on 21 January 2011 at the Vilnius Gediminas Technical University. The thesis is written in Lithuanian and is available from the author upon request. Chapter 1 gives the analysis of road classifications in Europe and other countries of the world, the development of road classification in Lithuania, also the sustainable safety principles and driving conditions on low-volume roads the aim and tasks of the work are formulated. Chapter 2 presents analysis of road alignment elements and road structure elements, also their influence on driving conditions and visibility. Chapter 3 describes methodology of experimental research aimed to determine, analyze and model the quality of the existing low-volume road alignment, parameters of road structures and characteristics of road pavements. Chapter 4 gives data obtained by the experimental research, data analysis, evaluation and the models for the improvement of driving conditions in designing and reconstructing low-volume roads.

Keywords: low-volume roads, design speed, safety criterion, horizontal alignment, vertical alignment, stability of road shoulders, visibility on longitudinal profile, reduction of dustiness, calcium chloride (CaCl_2), calcium lignosulphonate (CaL_g).

State of the problem

Lithuania's road network of national significance is sufficiently well developed ($> 21\,000$ km) and over the past 10 years has been changing insignificantly. A major part (~64%) of national roads has asphalt pavement, however, they are not safe. Even on the low-volume roads with the average annual daily traffic less than 10 000 vehicles per day (vpd) under unfavorable driving conditions when driving at a speed of less than 70 km/h a large number of road accidents occurs. The low-volume roads are frequently unsafe, the driving conditions are bad and they do not serve their function, i.e. access.

The work studies an important problem of the civil engineering science – factors, their influence on identifying which roads will be attributed to the group of low-volume roads, and the parameters of low-volume roads having the effect on traffic safety. The distribution of roads in country, parameters of low-volume roads influence on traffic safety will suppose further means and measures for the improvement of low-volume roads and the driving conditions.

Design, reconstruction, building, repair and maintenance of roads are related to the implementation of strategies of traffic safety policy. In this respect the largest responsibility lies on a road designer who, during the process of design, has to reconcile the expectations of many interested groups (customers, future road users, road maintenance enterprises, public institutions, etc.) in order to reach the efficiency of economic and social objectives over the lifetime of road.

The practice of European countries, based on sustainable safety, shows that they have gained extensive experience in implementing a preventive traffic safety strategy, starting with the design of roads and road networks and ending in audits. Based on the analysis of this experience there is a necessity to study and analyze Lithuania's roads according to the road function and geometry.

Dissertation is topical in the aspect of Lithuania's road network and the tendencies of its reorganization, taking into consideration a particular significance of low-volume roads with gravel or asphalt pavement which serve the function of access and provide access services determined

by the characteristic features of their functionality. The best way to create the sustainably safe traffic conditions on low-volume roads is to study them in view of the current European experience, to assess them in the aspect of the improvement of traffic safety and driving conditions and to improve them taking into consideration their geometric parameters, the curvature of road alignment and the type of pavement. The problematic questions which rise in the course of design and operation of low volume roads and are related to the assurance of safety criteria, correspondence of the elements of horizontal and vertical alignment to traffic, assurance of visibility conditions and stability of road structures will be answered by using the developed models for the improvement of driving conditions on low-volume roads.

Research object – Lithuania's road network of national significance; low-volume roads selected by the prevailing relief; gravel roads on which the dust-reducing chemical materials were used; low-volume roads selected for the experimental research of correspondence of road elements to traffic safety; low-volume asphalt roads selected for the investigation of the strength of shoulders.

Aim and tasks of the work – having studied the geometric parameters and structures of low-volume roads to propose models for improvement of driving conditions and to suggest practical actions based on the sustainable safety principles. The following tasks were solved to achieve the aim of this work:

- 1) determination of tendencies and perspectives for the improvement of driving conditions (traffic quality) on low-volume roads (reconstruction of low-volume roads, paving of gravel roads, the use of dust-reducing measures);
- 2) investigation of the correspondence of low-volume roads to traffic safety and driving conditions in the aspect of the improvement of driving conditions;
- 3) investigation of measures to improve visibility and driving conditions;
- 4) experimental research of the influence of the main elements of low-volume roads (horizontal alignment, vertical alignment, cross section, visibility) on safe driving speed, data analysis and evaluation;
- 5) experimental research of the reduction of dustiness on low-volume gravel roads in order to improve visibility and driving conditions, data analysis and evaluation;
- 6) experimental research of the strength of shoulders on low-volume asphalt roads, data analysis and evaluation;
- 7) models for the improvement of driving conditions on low-volume roads based on the generalization of the results obtained.

Methodology of research

The following research methods were used: mathematical statistical, comparative analysis, experimental planning; experimental-laboratory, experimental measurements of

design, shoulders and gravel pavements on low-volume roads.

For the analysis and modeling of research data the statistical and optimization methods were employed. For the determination of the efficiency of factors influencing the reduction of road dustiness the factorial modeling was employed.

Scientific novelty

The following results important for the civil engineering science were obtained:

- 1) a new classification of Lithuania's roads of national significance according to their function is suggested by distinguishing low-volume roads which provide access services and by defining their geometric parameters and design speeds;
- 2) methodology for the determination of design level of low-volume roads in designing their alignment is presented. Monograms for the determination of visibility on vertical curves are presented;
- 3) mathematical models are given for the selection of reagents to reduce dustiness on low-volume gravel roads and to improve driving conditions;
- 4) traffic safety assurance measures are suggested to be used on roads with a minimum width of traffic lane by erecting shoulders of the sufficient strength;
- 5) model for the design of low-volume roads is presented aimed to guarantee the proper driving conditions;
- 6) model for the use of low-volume roads is presented aimed to guarantee the proper driving conditions.

Practical value

A practical use of research results would allow to improve the quality of design solutions taking into consideration the correspondence of road alignment elements to driving conditions:

- 1) functional classification of roads of national significance is created. It could be used for preparation of new technical regulations;
- 2) model for the determination of parameters of road alignment elements is given aimed to achieve the required driving conditions;
- 3) monograms are created for determination elements of vertical alignment. Road design standards of the Republic of Lithuania could be supplemented with normative requirements for the selection of the elements of vertical alignment aimed to ensure visibility;
- 4) mathematical model for the reduction of gravel road dustiness by selecting a dust-reduction material and its amount is recommended. The use of adequate materials helps to improve driving conditions;
- 5) the use of research data enables to erect shoulder structures having sufficient strength and resistance to damages.

Extraction of low-volume roads in road network.

Formulation of aim and tasks of the work

Classification of motor roads in systems, functional classes or geometric types facilitates communication between engineers, designers, road maintenance enterprises and road users. For solving various tasks related to rural and urban roads the different road classification schemes are used. Classification of roads by location (city street, rural road, motorway) based on the geometric parameters of roads is useful to identify the road function and the requirements for road design. Classification of roads by significance is used to define the activity of road maintenance enterprises, the road maintenance level and financing methods, the level of road facility and road service. Grouping of roads by their function is intended for cargo transportation related to production and consumption. Functional road classification is very important to the planning of national economy since a detail plan of cargo transportation reflects the economic and social development of the country.

Having generalized road classifications used in different European countries, it was determined that at present there is no unique road classification system in Europe, since the aim of many of the currently used functional road classifications is only aimed at dividing roads. The low-volume roads are not distinguished as a separate group of roads having specific characteristics. However, in the classification of each country the low-volume roads can be distinguished by three features. The first feature is location as these roads mostly join small towns, farmsteads and other objects with higher-significance roads. The second feature – road function. The main function of these roads is to ensure access to objects. The speed limit is the third feature. In different countries the speed limit differs, though it is seldom higher than 70 km/h and never exceeds 90 km/h.

After the restoration of independence of Lithuania in 1990, the first Lithuanian regulatory document on road design was issued only in 1996. Until now, two more documents regulating a design of roads have been issued. In a period of 20 years, the principles of road design have changed the permissible speed limitations were rejected, as well as the vehicle speed v_{85} and the assessment of route curvature change. The road classification has also changed, the roads are not further grouped by their location in respect to residential areas, the number of road categories and types of cross section has also changed. The currently valid *Kelių techninis reglamentas KTR 1.01:2008 "Automobilių keliai"* [Road Technical Regulations KTR 1.01:2008 "Motor Roads" (RTR)] is the first to divide roads according to their function; however, there is no clear relation between road category and road function.

Analysis results of the Lithuanian road classification showed that low-volume roads correspond to the regional roads of national significance, the function of which is accessibility. These are asphalt or gravel roads. Roads of category IV also correspond to the group of roads with a distribution function. Therefore, low-volume roads by their

function can be access roads partly serving a distribution function and distribution roads partly serving access function.

Modern roads are the complicated engineering structures designed in a way that the solutions of road elements guarantee safe traffic and min costs of cargo and passenger transportation. Almost 90% of accidents are related to human factor, i. e. an error made by human. Thus, human is the weakest chain in the whole transport system. Besides, human is not able to quickly change and adapt himself to new conditions: many of the efforts to change human behavior resulted in only small benefit or failure. Human limitation is obvious; therefore, in a sustainably safe transport system human is the most important element to which the other elements are adapted.

The approach of sustainable safety, created in Netherlands in 1990, has two aims: to as much as possible reduce driving errors and to mitigate accident consequences.

The system of sustainable safety could be formed with the help of the following sustainable safety principles (Wegmann *et al.* 2005):

- functionality: functionality of the road system is important in the fact that the real use is consistent with the planned one. There are three functional groups of roads: through (flow), distribution and access roads. Each road shall serve only one function;
- homogeneity: homogeneity of the road system is necessary to avoid large differences in speed, driving directions and road users (mostly by separating incompatible road users and if this is impossible or undesirable – by forcing motor transport to slow down);
- predictability: to seek for the same type of road alignment having a unique combination of characteristics and limited number of road types in order to avoid mess and to increase perception possibilities.

Therefore, it is important to study the driving conditions on low-volume roads, to determine factors and directions necessary for the implementation of tendencies of improving driving conditions and to suggest practical actions based on the sustainable safety principles.

Theoretical analysis and substantiation of the improvement of low-volume road function

A lot of road accidents are caused by driving errors, therefore, people must know and understand the consequences of driving behavior for themselves and for other road users (Terlow 1990).

The research results indicated than on double-lane roads 50–60% of road accidents occur on curves (Lamm *et al.* 1999). The foreign scientists point out that by improving parameters of horizontal curves and transition curves it is possible to reduce accident density as well as accident severity. Consequently, the compatibility of driving speed

and geometric parameters of road alignment enables to control driving speed and accident probability.

Selection of driving speed depends on the compatibility of horizontal alignment and its elements. Compatibility of the horizontal alignment elements is one of traffic safety factors. In case if the horizontal alignment elements are compatible the probability of driving errors is reduced. Incompatibility of the horizontal alignment elements is increased if there is no successive transition between the elements of horizontal alignment (Gintalas 2010). In practice, incompatible elements of horizontal alignment lead to unsafe driving due to potentially large speed variations. Investigations of foreign scientists showed that geometric compatibility of horizontal alignment line is one of the attributes of traffic safety (Fitzpatrick *et al.* 2000a).

The method of safety criteria has been developed to assess compatibility of the horizontal alignment elements and to reduce the risk of accidents on curves (Cafiso *et al.* 2006; Fitzpatrick *et al.* 2000b; Gintalas *et al.* 2007; 2008; Lamm *et al.* 1999; 2007):

- the safety criterion I (SC I) – the design speed shall be stable on the longest possible road sections. Stability of the design speed v_d is determined by comparing the selected design speed v_d to the speed v_{85} on each element of the road alignment;
- the safety criterion II (SC II) – the speed v_{85} shall be stable between the two adjacent road elements;
- the safety criterion III (SC III) – criterion of driving stability and cost-efficiency. Criterion of dynamic stability on curves compares the acceptable lateral force coefficient to the lateral force coefficient estimated at the speed v_{85} .

In the design of roads and preparation of road reconstruction project it is also important to assess the vertical alignment of roads. In order to ensure safe traffic conditions on vertical alignment the sight distance requirements should be met: stopping sight distance and passing (overtaking) sight distance (Fabro *et al.* 1997; Lamm *et al.* 2002). According to the RTR of Lithuania the stopping sight distance and the passing (overtaking) sight distance shall be ensured for the vehicles driving at the design speed v_d .

Based on RTR the elements of vertical alignment are designed taking into consideration the design speed v_p and the sight distance. In Lithuania the stopping sight distance and passing (overtaking) sight distance shall be ensured for the vehicles driving at the design speed of v_d on a road segment with the longitudinal gradient i . However, the elements of sag vertical curve or crest vertical curve (change in longitudinal gradient, radius and length of vertical curve) are not considered.

The min radii of vertical curves $R_{v,min}$ are defined from the required sight distance. The min radius of crest vertical curve depends on the stopping sight distance and the required min radius is defined from the passing (overtaking) sight distance. The min radius of sag vertical curve is defined from the sight distance illuminated by the vehicle lights in a dark period of the day. In the analysis of parameters of vertical curve elements two cases are applied:

- when the sight distance (the stopping sight distance or passing (overtaking) sight distance) is shorter than the length of vertical curve;
- when the sight distance (the stopping sight distance or passing (overtaking) sight distance) is longer than the length of vertical curve.

The shoulder is an important element of road system allowing for emergency parking and additional zone for vehicles, serving for the structural strength of road pavement, for the drainage to discharge water from road pavement, ensuring better visibility, functioning as bicycle path or increased width of traffic lane to serve agricultural machinery.

The structural strength and stability of road shoulder depends on pavement structure and strength of subgrade. Insufficient structural strength of road pavement causes deformations of shoulders, in the result they become unstable and changes in road pavement evenness appear (Васильев, Сиденко 1990).

Design and construction of granular shoulders is cheaper than asphalt ones, however, maintenance is more expensive as granular shoulders have more performance-related problems. The problems are as follows: erosion, caused by wind and water, ruts, edge breakage, variability of grading. Therefore, granular shoulders require better maintenance.

Granular shoulders are usually used on low-volume roads. Material grading, compaction method and type of the structure are the main factors to ensure better quality of the shoulder. The scientists of the foreign countries have determined that the shoulder of insufficient quality is the cause of many accidents. The most frequent damages to gravel shoulders are ruts and pavement edge breakage (Souleyrette *et al.* 2001). Rutting and pavement edge breakage are determined by the following reasons (Giroud, Han 2004; White *et al.* 2007):

- settlement of shoulder pavement;
- poor grading of the mineral material;
- decrease in the bearing capacity of pavement base;
- insufficient thickness of road pavement or its base courses;
- erosion of shoulder pavement caused by poor draining conditions;
- large traffic volume;
- oversize vehicles travelling on the shoulder.

Based on data submitted by the Lithuanian Road Administration on 6 December 2010, in Lithuania the roads of regional significance made 68.6% of the total network of national significance and 35.8% of regional roads have gravel pavement. All the roads with gravel pavement belong to the regional roads, i. e. low-volume roads. All the roads with gravel pavement belong to the regional roads, i.e. low-volume roads.

Many researchers point out that the performance of gravel roads are different due to climatic conditions, traffic volume, materials used for the structure and other reasons, therefore, in order to solve problems of the currently used gravel roads, the process of gravel road deterioration has been analyzed and normative requirements have been

set for gravel road reconstruction, repair and maintenance (Paterson 1987; Thompson, Visser 2007).

The driving conditions on gravel roads are related not only to the road technical parameters, pavement corrugation, rutting and potholing but also to dustiness. In many countries the condition of gravel roads is rated good and the driving conditions are rated suitable only in case if the gravel road is not dusty (Žilionienė *et al.* 2007).

The long-known measures to reduce dustiness are pavement irrigation and profiling. The function of mineral dust binders is to absorb moisture from the environment and to join the particles of mineral dust. For this purpose the hygroscopic salts (chlorides, lignosulphonates) and bitumen emulsions are commonly used in the world.

Taking into account environmental aspects, economic indicators and the costs of implementing dust-reducing measures, the amount of dust-reducing materials shall be small and they shall ensure the reduction of dustiness.

The efficiency of dust-reducing materials worsens when it rains as they are washed away, except bitumen emulsions, therefore, it is important to be aware of the effect of the duration of rainless days on gravel road dustiness. Vehicle traffic, type and amount of dust-reducing material, frequency of gravel road profiling, grading of the mineral material of gravel pavement influence the lifetime of gravel pavement treated with dust-reducing material.

Experimental research of low-volume roads

Section 3 gives methodologies developed in the course of work, i.e.:

- for distinguishing the study object in the Lithuanian road network;
- for investigating road alignment (horizontal and vertical) elements on low-volume roads;
- for investigating cross section of roads;
- for investigating dust reduction on gravel roads.

From the list of Lithuanian roads of national significance the low-volume roads only with the characteristic features were selected: the road of regional significance, the average annual daily traffic is not exceeding 10 000 vpd, having asphalt or gravel pavement.

The alignment of low-volume roads is influenced by the relief; therefore, the relief was taken into consideration when selecting the study roads. According to the map of vertical zoning the territory of Lithuania was divided into three zones which are distinguished by the average differences in relief heights.

Investigation of horizontal and vertical alignment elements of low-volume roads was carried out in the following stages:

- with the use of mobile laboratory and GPS technology the position of longitudinal and vertical alignment line was identified;
- longitudinal and vertical alignments of the study roads were modeled using the Civil 3D software;
- using the Civil 3D software the parameters of longitudinal and vertical alignment elements were determined.

Having determined the parameters of horizontal alignment elements, the design level of roads were analyzed by applying traffic safety criteria, and according to the parameters of vertical alignment elements the stopping and passing (overtaking) sight distances were defined.

Investigation of the cross section of roads was carried out in the following stages:

- selection of measuring sites;
- measurement of shoulder width and cross fall;
- measurement of the deformation modulus of shoulder pavement;
- taking of the material of shoulder pavement layer;
- measurement of the thickness of shoulder pavement layer;
- measurement of the deformation modulus of shoulder base.

Investigation of the reduction of dustiness on gravel roads was carried out in the following stages:

- selection of experimental sites;
- taking of the material of gravel pavement;
- investigation of moisture and grading of the material of gravel pavement;
- determination of the duration of rainless period;
- mathematical modeling of three variables (type and amount of reagents used to reduce dustiness, duration of rainless period).

Modeling of driving conditions on low-volume roads

For the investigation of the effect of road alignment parameters on the driving speed on low-volume roads 30 low-volume roads were selected. The roads were selected according to the map of vertical zoning of Lithuania where three zones were distinguished. The total length of study roads is 560.65 km.

The selected roads were analyzed according to three safety criteria:

- the safety criterion I (SC I) – stability of the design speed v_d ;
- the safety criterion II (SC II) – stability of the speed v_{85} ;
- the safety criterion III (SC III) – dynamic stability on curves.

It was determined that according to the SC I the design level of low-volume roads is more dangerous than fair. This shows that the flow speed v_{85} in the horizontal alignment elements is 10–20 km/h higher than the design speed v_d (Fig. 1).

Having identified and assessed how the elements of horizontal alignment of the study roads correspond to traffic safety, the analysis was made of the change of safety criteria in the selected zones in the territory of Lithuania. To this purpose, the hypotheses were tested if the design levels are similar in all three zones according to all three SC and the general design level. The results of tested hypotheses show that the SC I and SC III in different zones differ insignificantly, since the obtained statistical data does not contradict the hypotheses on uniform distributions (in terms of parameters).

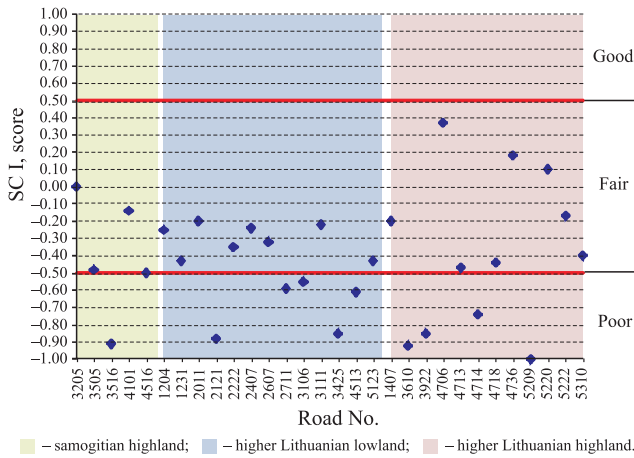


Fig. 1. Design level of the study road elements according to the SC I

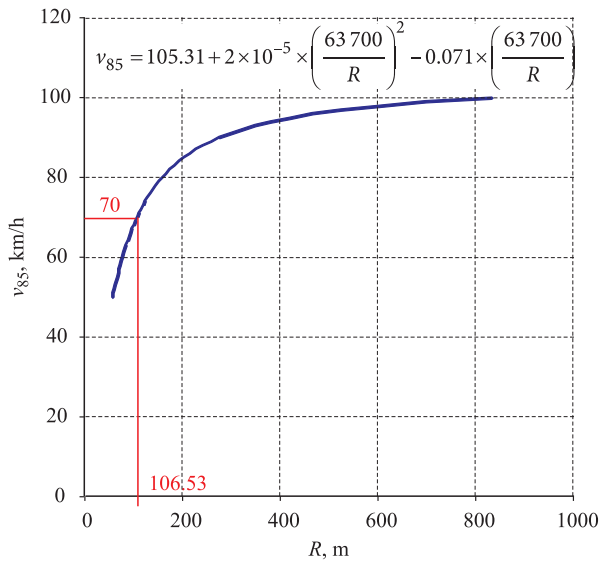


Fig. 2. Dependency of v_{85} on R when the design speed v_p is 70 km/h

When solving minimization problem aimed to determine the radius of horizontal curve at which the difference between the design speed v_d and the speed v_{85} would be as small as possible, it was determined that at the design speed v_d of 70 km/h, the curve radius must be 106.53 m (Fig. 2).

For the analysis of moisture content variation in gravel pavements due to the amount of rain and precipitation, duration of rainless period, also due to the amount of reagents helping to accumulate moisture and to retain it in pavement, full factorial experiments of moisture content variation were performed in gravel pavement treated with calcium chloride (CaCl_2) and calcium lignosulphonate (CaL_S).

In order to determine moisture content in gravel pavement D_{GP} treated with CaCl_2 , due to the variation of the amount of CaCl_2 and duration of rainless period, the following dependency can be used:

$$D_{GP} = 2.1 + 0.2 \times AR - 1.5 \times T_{RP} - 0.06 \times AR \times T_{RP}, \quad (1)$$

where AR – index of amount of reagent, i.e. CaCl_2 in gravel; T_{RP} – index of duration of rainless period, in days.

The model developed for the retention of moisture content in gravel pavement shows that the amount of calcium chloride in gravel pavement has a positive effect. The reduction of moisture content in gravel pavement is highly influenced by the duration of rainless days.

With the use of max amount of CaCl_2 in gravel pavement the moisture content in 3 rainless days reduces up to 3.9%, i.e. almost twice compared to the optimum moisture content. The reduction of moisture content is considerably more influenced by the duration of rainless days than by the amount of CaCl_2 . Having increased the amount of CaCl_2 from the min to the max the moisture content in gravel pavement increases only by 0.6%, and having increased the number of rainless days from 3 to 7 the moisture content in gravel pavement reduces by 3.0% roughly.

Mathematical model showing the amount of variation in moisture content of gravel pavement D_{GP} due to the amount of CaL_S and duration of rainless period is:

$$D_{GP} = 1.4 + 0.2 \times AR - 1.2 \times T_{RP} - 0.2 \times AR \times T_{RP}, \quad (2)$$

where AR – index of amount of reagent, i. e. CaL_S in gravel; T_{RP} – index of duration of rainless period, in days.

The moisture content in gravel pavement is retained by a larger amount of CaL_S in gravel. The moisture content is better retained under a shorter duration of rainless period. However, in the best case (having used the max amount of CaL_S under the min duration of rainless period, i.e. 3 days) the moisture content in gravel pavement reduces up to 3%, i. e. the moisture content is 1.3 times lower than using CaCl_2 for this purpose.

Analysis of the strength of shoulder pavement and the structural strength of the shoulder showed that the average value of deformation modulus E_{v2} for the base is 78.7 MPa, for the pavement structure is 32.5% less and makes 53.1 MPa.

The shoulder pavement should increase the structural strength of the shoulder but the opposite result is obtained. It should be noted that the measured values of deformation modulus in all measuring points under the pavement are from 1.1 to 3.2 times higher than on the top of the shoulder structure. The below figure gives the dependency between those values (Fig. 3).

Based on the changes in the indices of the strength of shoulder base and shoulder structure, the structural strength of the shoulder can be calculated according to Harris model (3). It is obtained from the processed data of the strength and thickness of pavement layer that:

$$E_{v2(SS)} = \frac{1}{(a+b)E_{v2(SB)}^c}; \quad (3)$$

where $E_{v2(SS)}$ – structural strength of the shoulder, MPa; $E_{v2(SB)}$ – strength of the shoulder base, MPa;

a , b , c – Harris model coefficients: $a = 0.02387$, $b = -0.00027$ and $c = 0.91307$.

It is proposed a model for developing driving conditions in low-volume roads, based on made experiments and their results (Fig. 4).

Using this model there are estimated driving conditions on low-volume roads according to compliance with category of road, safety criteria, sight distance. Then it is determined the necessity of development of maintenance characteristics.

General conclusions

Having made the analysis of driving conditions on low-volume roads it could be stated that driving conditions are

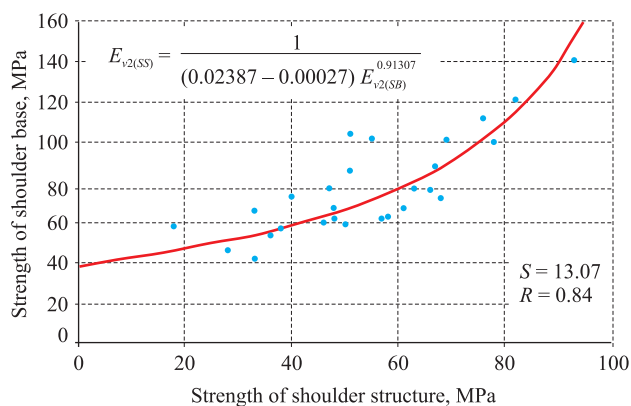


Fig. 3. The strength of shoulder base $E_{v2(SB)}$, MPa

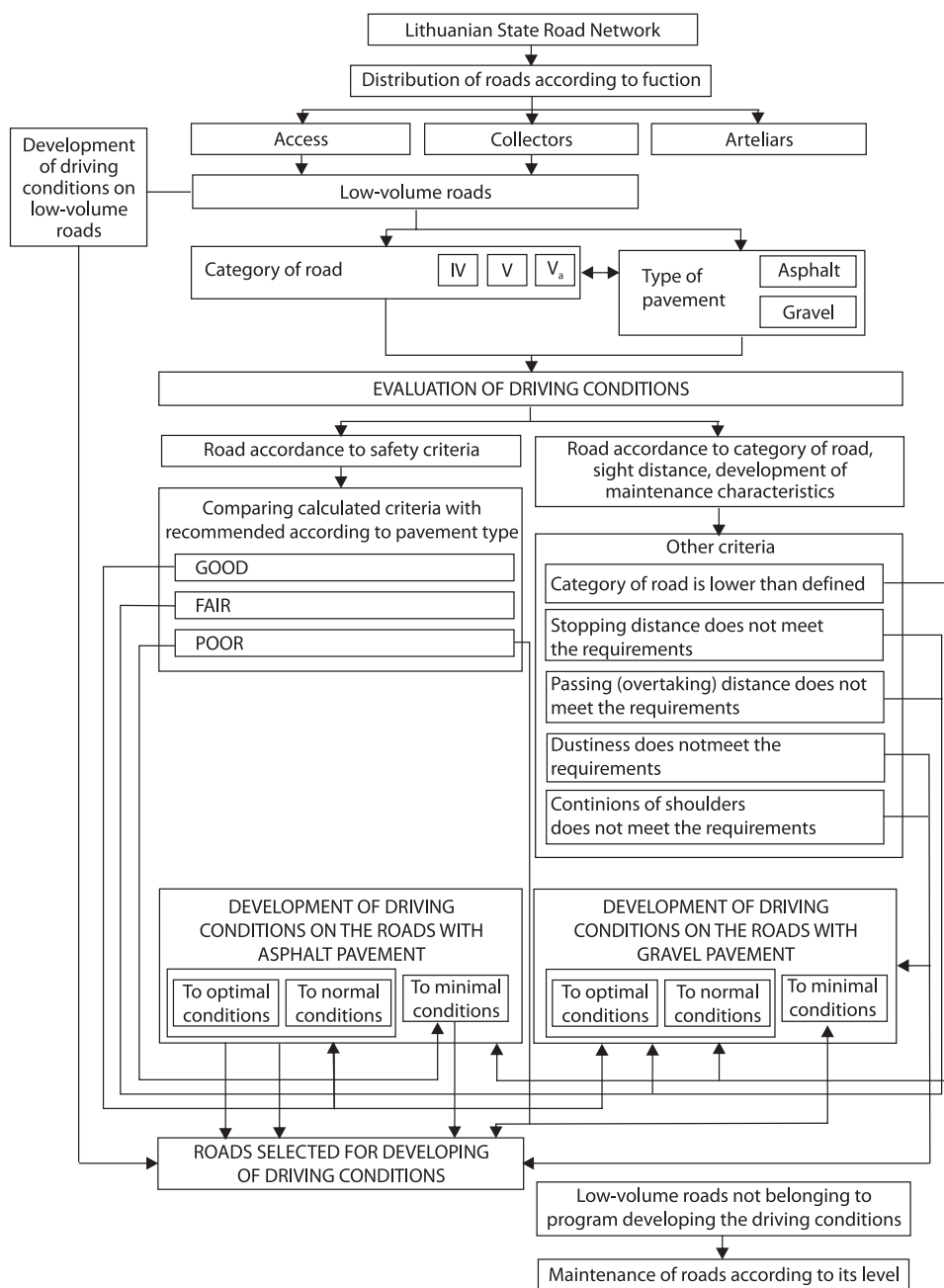


Fig. 4. Model for the improvement of driving conditions on the operating roads

ensured when valuating road design according to safety criteria, ensuring sight distance on vertical alignment, ensuring not only reliability of the carriageway but also of the shoulders and using dust-reducing materials on roads with gravel pavement. Low-volume roads in Lithuania with gravel and asphalt pavement make more than 68% of the total road network. When implementing the Gravel Road Paving Program it is planned to reduce the number of gravel roads to 30%. This shows that the gravel road reconstruction and improvement of driving conditions will remain relevant in future also.

The analysis of scientific literature on the topic of road alignment valuation allows to state that the role of the 85% flow speed is important for the low-volume roads also when the parameters of road elements are selected. Thus, it is recommended to use 85% flow speed while designing road horizontal alignment and supplement the policy on design of roads with this speed.

Requirements for the design of the vertical alignment elements given in the Road Design Standards of Lithuania do not ensure the safe driving conditions and sight distance. The requirements take no consideration of the length of elements and the difference of gradients. Thus, it is recommended to supplement the policy on design of roads with calculation method, which describes each vertical alignment, its length, grade, height of obstacle. This method analyzes the influence of elements to sight distance.

The analysis of research data showed that there are not ensured safe driving conditions on low-volume roads, because:

- according to the safety criterion I design level of 33% of the horizontal alignment elements is dangerous and 67% – fair; according to the safety criterion II design level of 3% of the horizontal alignment elements is dangerous, 37% – fair and 60% – good; according to the safety criterion III the dynamic stability on curve of 7% of roads is dangerous, 80% – fair and 13% – good;
- using method practiced in foreign countries it was determined that in 90% cases the sight distance in the vertical alignment do not ensure the safe driving conditions, because in 44% cases the sight distance is lower than the passing (overtaking) sight distance;
- cross falls of more than 80% of shoulders are smaller than 6%. Due to small cross fall water discharge slowly from the road, so more water get into the structure of the road. Thus the shoulder strength is getting weaker especially in autumn and spring;
- moisture of gravel pavement during 3 days reduces almost twice using max quantity of calcium chloride (CaCl_2) and reduces 2.6 times when using max quantity of calcium lignosulphonate (CaL_s).

Research of reducing dustiness on gravel pavement showed how the driving conditions depend on the weather conditions, type of the binder used and moisture content of gravel pavement. Dustiness due to the reduced moisture

in gravel pavements is determined not by the amount of dust-reducing materials used but by the duration of rainless days. When a dry period lasts for more than 7 days the effect of dust-reducing materials is insignificant in respect of moisture retention.

Research of the low-volume road shoulders showed that the strength of shoulder structure is weaker than the strength of shoulder base. The strength of shoulder base varies from 37.9 MPa to 119.5 MPa. The strength of shoulder structure varies from 17.0 MPa to 89.2 MPa. It is recommended to supplement the policy on design of roads with requirements for shoulders and its base strength.

Models for the improvement of driving conditions are developed for the designed and existing roads. Using these models the parameters of road design elements are selected according to design speed using these models. Also the criteria are determined according to which the safe driving conditions are guaranteed.

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