THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2013

8(2): 75–82

INFLUENCE OF FUNCTIONALLY OBSOLETE BRIDGES ON THE EFFICIENCY OF ROAD NETWORK. PART II: CASE STUDIES

Zenonas Kamaitis

Dept of Bridges and Special Structures, Vilnius Gediminas Technical University,
Saulėtekio al. 11, 10223 Vilnius, Lithuania
E-mail: zenonas.kamaitis@vgtu.lt

Abstract. This study is the first practical step in Lithuania to identify the characteristics causing the bridges to be functionally obsolete. A bridge of which current deck geometric characteristics, safety barriers or railings, underclearances, and roadway approach alignment are deficient and not consistent with current design standards (or traffic demands) can be considered as functionally obsolete. In Part I of this paper the criteria of functionally obsolete bridges, deficiency categories and assessment of deficient structures are presented. The Part II reports experience in city bridge stock of 83 structures for a short period of 2–5 years on this subject. Surveying revealed that 58.5% of bridge stock shows minor or obvious signs of functional aging. Evaluation and rating of city bridge stock was undertaken. Illustrative examples of functionally obsolete bridges are presented. Recommendations for improvement of the geometrical characteristics of bridges in existing Lithuanian design codes are envisaged.

Keywords: urban bridges, functional obsolescence, bridge widths, underclearances, safety features, approach roadway, condition rating.

1. Introduction

The road bridges are very important elements in every country's roadway network particularly at interchanges and river crossings and inevitably reflect network's capacity. It is commonly recognized that safety of existing bridges tends to originate serious problems in many countries both in economic as well as social and environmental terms. Many existing studies focus on the structural deterioration of road bridges, however, less attention is given for their functional obsolescence. Only limited research has been undertaken also in Lithuania on this subject.

As was stated in Part I of this study, a functionally obsolete bridge is the one that was built to standards that are not used today. These bridges may be structurally in good condition but do not meet the needs of current traffic and have to be renovated or even dismantled. As an example, three precast segmental two-lane bridges in good structural condition are considered as functionally obsolete and have to be removed (Brown 2002). This situation establishes the claim for the adoption of a rational and comprehensive scheme for the management of aging bridges.

Functionally obsolete bridges are those that do not have adequate lane or shoulder widths, clearances, safety features, approach roadway alignment or waterway adequacy. To quantify functional deficiencies of individual structures or a whole bridge population, the data should be collected during systematic and long-term inspections. This allows managing all bridge inventory given various traffic regulation, maintenance of structures and financial scenarios.

It seems that the most profound and systematic investigations and assessments of existing highway bridges are performed in US. All bridges in US by federal law have to undergo in-depth inspections that are performed at least once every two years. In 2007, according to ASCE there were 152 316 of the national 599 766 bridges – or 25.4% – that were considered substandard. Of these, a total of 79 792 approx 13.3% were classified as functionally obsolete.

In recent years, after a number of bridge collapses in the US, the increased attention has been also given to the existing stock of bridges in European countries. Numerous management systems have been developed throughout Europe. Although, it seems that in Europe the emphasis is greater on bridge structural deterioration. Less attention is attributed to their functional obsolescence.

The cases of functionally obsolete bridges in some countries are mentioned in Part I of this study with some references on this subject. The first attempt to analyze

ISSN 1822-427X print / ISSN 1822-4288 online doi:10.3846/bjrbe.2013.10

http://www.bjrde.vgtu.lt

the substandard underclearance bridges in Lithuania was undertaken by the author of this paper in 1995 (Kamaitis 1997). Experience shows that the functional requirements in the bridge codes are subject to change over time. For example, most of the existing bridges in Lithuania in post-World War II period are designed according to different codes adopted in 1948, 1953, 1962, 1984 and 2005 with increasing live load and geometric specifications. It is evident that much of the national bridge stock is now below an acceptable standard. In some bridges, the conditions in which the circulation takes place adversely affect the traffic capacity.

In Part I of this work the criteria of functionally obsolete bridges, deficiency categories and assessment of deficient structures using cost-based approach are presented. In order to illustrate the practical aspects of bridge obsolescence problems the case studies were undertaken. The Part II contains the findings based on the site inspections during 2005–2010 of urban bridge stock of total 83 structures. It was the first step in this effort which was to identify all functional obsolete bridges and to provide functional obsolescence evaluation for the inspected bridges in Lithuania.

2. Bridges used for studies

During 2005–2010 the first step was undertaken to identify functionally deficient bridges, including the characteristics and examples causing them to be functionally deficient.

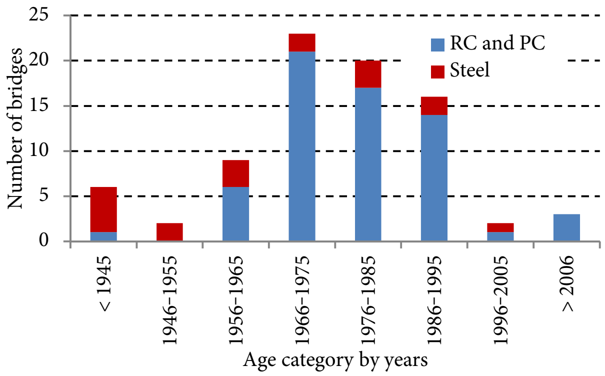

Fig. 1. Number of bridges by the year built

This study addresses 83 bridges located in city streets. A large number of bridges are made of concrete (41.5%) or prestressed concrete (31.7%) and steel (26.8%). The highest number of bridges was built during the peak construction period from the late 1966s through the early 1995s, but there are older bridges still in use (Fig. 1). Some bridges (about 20%), although designed and constructed more than 50 years ago, are still in good structural condition and continue to be specified in current application. The older bridges are designed to lower geometric standards of the time and actually they need to be posted or closed for some types of vehicles. Modernization has been patchy and partial. Normally, some portion of functional obsolescence could be curable.

Specifications on the basic geometry of bridge structures are included in the codes of each country. The design standards and required functional performance for bridges in Lithuania has been progressively revised, as shown in Table 1. Dimensional requirements for bridge deck widths, bridge openings and bridge railings normally are given. These requirements are governed by the requirements to traffic safety and considerations of economy.

For further studies 65 structures were selected. Footbridges and reconstructed bridges were excluded from the analysis.

3. Survey findings

3.1. Narrow bridges

Evaluation is applied to bridge roadway between railings, curbs or median barriers. The width of a bridge is compared to standards and is related to the amount of traffic it carries, number and width of lanes as well as presence and width of shoulders. The widths of shoulders vary according to category of road, traffic volume and have to accommodate traffic safety. The width of travel way and shoulders should be consistent with the existing cross-section of the adjacent roadway. The bridge is rated as functionally obsolete if the approaching traffic needs to make driving adjustments (slow down, stop, sharp turn) before crossing the bridge.

Table 1. Design geometrical parameters for 2-way urban bridges on arterial roads

Codes	Shoulders, m	Railings, m	Street underclearances		Railroad underclearances	
			Vertical, m	Lateral*, m	Vertical, m	Lateral**, m
CH 200-62 (1962–1984)	no requirements	curbs 0.25 m height	4.5	no requirements	6.3	3.1
CHuП 2.05.03-84 (1984–2001)	0.75	0.75/0.60***	≥ 5.0	≥ 1.5	6.4	3.1
STR 2.06.02:2000 (2001 up to now)	≥ 0.50	≥ 0.75/0.50***	≥ 5.0	9.0	6.4	3.1

* – distance from the edge of the adjacent traffic lane to the face of bridge pier where the bridge pier is not protected by safety barrier;

** – distance from the centerline of track to the face of bridge pier;

*** – 0.75/0.60 = safety barrier/parapet.

Narrow two-lane road bridges are those that are 7.0 m wide or less, have poor approach geometries, narrow lanes, narrow or no shoulders or do not accommodate pedestrian or bicycle traffic. These bridges are usually older and built until 1983 using past design standards.

There are 13 narrow historical bridges. Any bridge built before 1962 is likely to be lacking breakdown shoulders. A very good example is the bridge built in 1930 (Fig. 2). As the picture shows, the bridge is so narrow that people are reluctant to be on the bridge when a truck is crossing the bridge in the opposite direction. It accentuates the delays caused by accidents, makes staging of resurfacing and repairs more difficult, and can add chokepoints or bottlenecks.

It is well known that there is definite relationship between bridge widths and vehicle accident rates. Unfortunately, there is a lack of collision records and costs associated with narrow bridges.

3.2. Underclearances

This feature is a measure of vertical or lateral clearances for any road passing under the bridge. Minimum underclearances are specifying to ensure that the structures are not struck by vehicles, vessels or trains which pass below them. On the other hand, appropriate clearance should assure the comfortable and without any restriction traffic circulation. If traffic must be controlled by clearance and speed limit signs, the bridge should be considered at some measure as functionally obsolete.

The vertical clearance is measured down from the lowest part of the bridge superstructure to the roadway surface. Note that the real values of vertical clearances sometimes vary due to snow built-up or resurfacing work, deflection of loaded bridge superstructures. In some states of the US, if vertical clearance is less than 4.88 m it is considered as functionally obsolete. In UK (Retting *et al.* 2000) the bridges with clearances below 5.05 m are considered “at risk”. The most common height of bridges that are struck is that with a clearance between 3.65 and 4.27 m. In Ireland the min safe headroom is 5.0 m. In Australia the min height clearance over roads is 4.9 m. Although, for major freight routes a preferred min height clearance would be 5.5 m. Otherwise, traffic must be controlled by clearance and speed limit signs.

As a result of insufficient vertical or lateral clearance highway and railway bridges over roads are subject to risk of damages caused by vehicular impact. Every year in many countries substandard bridges are hit by lorries or trailers which are too high to pass underneath the bridge. The number of collision accidents has been recorded in many countries involving sometimes long-term traffic restrictions, fatalities, injuries, serious environmental damages, and large economic losses (e.g. Das, Gibbs 2001; El-Tawil *et al.* 2005; Ghose 2009; Horberry *et al.* 2002; Kamaitis 1997; Martin, Michell 2004; Retting *et al.* 2000; Trouillet 2001; Xin-Zheng *et al.* 2007; Yang, Qiao 2010). It seems that the incidents due to inadequate circulation underclearances to bridge sub- and superstructures are increasing. The damage done to the bridges is not always obvious but can be serious. Sometimes these accidents are very costly. For example, according to Maryland (US) bridge inspection report (2001), from 1496 bridges a total of 309 bridges (20%) were found to have some degree of over-height impact damage (Fig. 3). The annual number of over-height accidents increased by 81% over the 6 year. There were also 19 injuries. The two distinct peaks around 4.42 m and 5.03 m depend on the type of route underneath the bridge. The main causes of bridge strikes are the driver’s lack of knowledge of the exact height of their vehicles loaded by equipment, poor bridge warning signs or markings, and bends of approach way located before a bridge (reduce its visibility, particularly at night or in fog). Research work in the vehicle collision with bridges continues. Several aspects, such as predicting and modeling of accident rates influenced by traffic, road and bridge geometric as well as environmental factors, the magnitude of the collision loads, collision protection measures are not yet well established.

The bridges inspected in this study (Fig. 4) included 65 on the overpasses between them 25 (38.5%) that have limited overhead clearance and could be involved in

Fig. 2. Urban steel bridge (1930) restricted to one-way traffic in opposite directions: narrow clear roadway (5.8 m) and sidewalks (0.5 m); no shoulders, no sidewalks and lane markings along the bridge

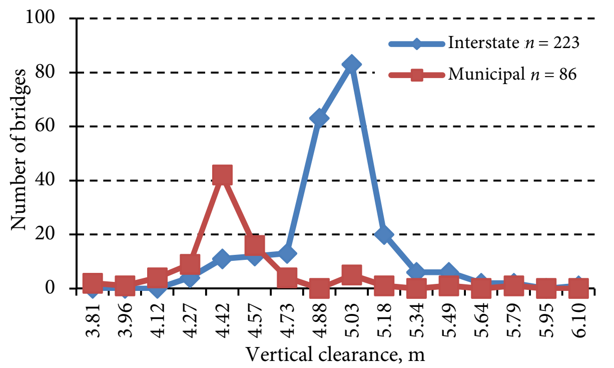

Fig. 3. Vertical clearance of bridges struck by over-height vehicles

over-height collision. A total of 15 (23%) bridges were found to have some degree of impact damage, between them 8 include serious collisions and had repair made at some point in time (Fig. 5). The most common height of bridges that are struck is that with a clearance between 4.5 and 5.0 m. As a rule all these bridges are built before 1972. Note, that min vertical design clearance for new overpasses in Lithuania since 1984 is ≥ 5.0 m.

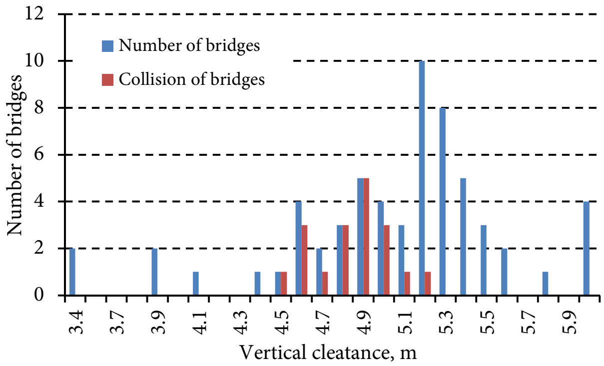

Fig. 4. Total number of inspected bridges and number of bridges damaged by over-height vehicle accidents versus vertical clearance of obsolete bridges

Fig. 5. Collision damage of concrete footbridge with vertical clearance of 4.97 m

Fig. 6. Example of the bridge with insufficient lateral underclearance

Horizontal or lateral clearances are measured from the through roadway to the substructure and are evaluated unless the bridge is over highway or railroad. Example of the bridge with restricted lateral underclearance that causes the collision risk between passing vehicles and the bridge piers is shown in Fig. 6. Average Daily Traffic ADT = 13 140 vpd (vehicles per day). Speed is reduced from 60 km/h to 40 km/h at the distance of 200 m to the underclearance restricted bridge. In this simple case the road user delay time (Eq (3) Kamaitis 2012) is of 12 620 hpy (hour per year) and vehicle operating delay time is of 15 850 hpy.

Although the vehicle collisions with bridge piers are rare comparing to all truck collisions with bridges, the example of this type of damage is presented in Fig. 7. It was found that under geometry – lateral clearance of 7 (10.8%) inspected bridges are functionally obsolete in this category.

Traffic on or over the under-standard bridges must be controlled by clearance and speed limit signs. Signed high risk bridges with restrictions of clearances force the drivers to choose alternative routes taking into account “problematic” bridges.

3.3. Safety barriers and railings

Traffic safety feature is a measure of bridge railings condition. Safety barriers and railings according to the requirements of current standard are provided between roadway and sidewalk as well as at the outside edges of the deck along the roadway to contain vehicles to the roadway. The use of barriers and railings are governed by the criteria that they have to prevent pedestrians, bicyclists or motor vehicles from falling off the bridge deck and to separate vehicular lanes from pedestrians with the aim to prevent their collision. Insufficient barrier height leads to the result as shown in Fig. 8. In the old bridges where the barriers are not installed, the height of the sidewalk should be matched to that of the adjacent roadway for the sake of safety and may be tolerated only for single lane bridges on low-volume traffic roads.

It is recognized that the safest two-way roads with high traffic volume are those with a central guiderail or concrete barrier wall. Bridges without a central guiderail are more risky and more dangerous for users. A recent accident observed on one of the city bridges in which 13 vehicles were involved was not fatal due to the presence of central guiderail that excluded vehicle collision in opposite directions. Most of inspected bridges, some of them on the main arterial streets, are two-way without vertical grid separator. Only few bridges of the stock inspected meet this consideration.

3.4. Approach road alignment

This feature applies to those bridges that do not function properly or adequately due to the road located within the influence zone of the beginning or end of a bridge (in the bridge area adjacent to the bridge) considering horizontal and vertical alignment of approaches. The basic criteria of obsolescence are how the alignment of the roadway approaches to the bridge i.e. approach curvature, lane and shoulder widths relates to the traffic circulation in the sector of roadway the bridge is on. The bridge geometrics should be compatible with its approach roads. Entrance and exit of a bridge should be without any widening or posting of any sign to control traffic. Speed limit should be taken as a measure of existing functional obsolescence.

However, the number of cases exists when crossing the bridge requires a major speed reduction due to the presence of intersections near the bridge or horizontal or vertical curvature of the roadway at the bridge reducing sight distances for vehicles. The driver will find himself constrained to slow down, to avoid flying off at a tangent and sliding downward across the pavement when the surface is slippery from rain, snow or ice. Fig. 9 shows an example of the bridge on the "*S*" shaped street over the main road. The photo shows that there is a severe bend in the road and the reduction of allowable traffic speed from 70 km/h to 40 km/h is envisaged by signing.

Another example – the bridges connected with approach street circle interchanges that are very frequently found in the city street network. The advantages and disadvantages of traffic circles at unsignalized city or road intersections are discussed in many publications (e.g. Çalişkanelli *et al.* 2009; Daunoras *et al.* 2008; Dell'Acqua, Russo 2010; Jurevičius, Bogdevičius 2007; Žilionienė *et al.* 2010 among others). These had their origin in city plan in the past and their drawbacks became apparent. Traffic is slowed by the curve of the circle and then by the vehicles entering or leaving a bridge. Frequently, during peak traffic periods a complex situation on the bridges is created. As an example, the river bridge of two way four lane, 14 m wide and 174 m long with the average *ADT* = 16 100 vpd is considered (Fig. 10). The bridge and interchanges adequacy was evaluated based on the average speed of vehicles (individual cars, commercial vehicles – light and heavy, buses/trolleybuses) and traffic delay on the bridge during the traffic jams. It was observed that the bridge experiences traffic jams almost all day (from 6:00 to 22:00). Traffic congestion causes a delay approximately 9500 of vehicle-hours and 21 150 of user-hours each year. The user cost related to traffic jam on the bridge reaches about €528 thousand each year. If we assume that socio-economic losses are about 50% of user costs a total of approximately of €800 thousand are lost every year. It is evident that traffic congestion increases the cost of mobility to everyone and reduces the possibilities of using bridge resources as the bridge is not functioning as intended.

Fig. 7. Collision damage of bridge pier column

Fig. 8. Car accident on the bridge built on sharp street bend and insufficient parapet height (photo from Delphi)

Fig. 9. Example of the bridge on the severe bend in the road and as result with posted traffic speed

The approaches for pedestrians at bridge sidewalks and footbridges should be briefly mentioned also. Sidewalks and footbridges should be accessible to all users, including those with disabilities, people using wheelchairs, strollers, bicycles. The Lithuanian Code *STR 2.06.02:2000 Tiltai ir tuneliai. Bendrieji reikalavimai* [Bridges and Tunnels General Requirements] requires the footbridges to be equipped with curb ramps. It is observed that in the older crossings the mentioned users have a limited access to pedestrian bridges.

4. Functional obsolescence evaluation

After field inspection of urban bridge stock and analysis of the historic condition state data, each bridge was assessed for functional deficiencies using condition rating system based on common opinion of 2–3 experts. In this investigation all bridges are rated using the following scale:

5 excellent – superior or equal to current design standard and present traffic flow criteria;

4 good – somewhat equal or better than present minimum criteria to tolerate being left in place as it is; this indicates that the bridge may show some functional deficiencies in the rush hours;

3 satisfactory – somewhat below minimum acceptable condition; basically intolerable for at least one geometric category;

Fig. 10. Illustration of circle-shape unsignalized intersection in the bridge area leading to bridge-bottleneck and traffic jam formation

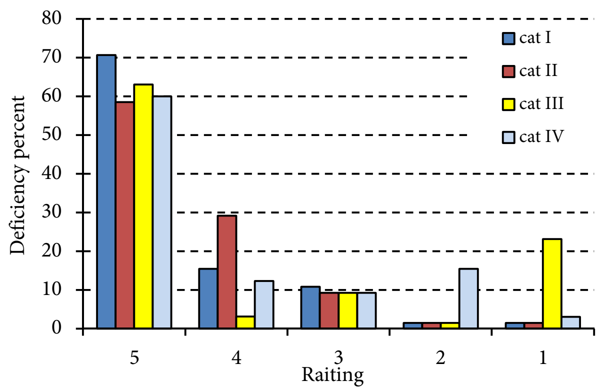

Fig. 11. Distribution of bridges by rating number for each of bridge geometrical category

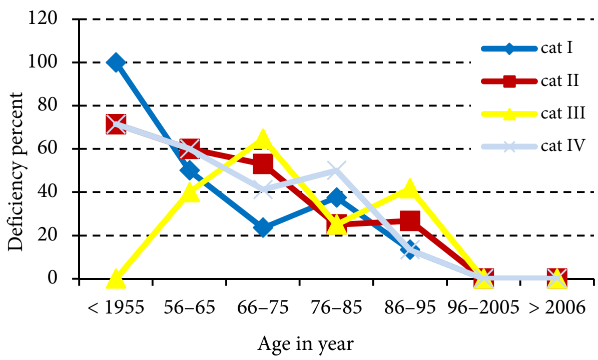

Fig. 12. Functionally obsolete bridges by geometrical category and age group

2 poor – below the design standard and current traffic demand requiring special signing;

1 serious – the bridge does not meet currently acceptable standard and not functioning as intended (repeated accidents are observed) requiring high priority of signing or reconstruction/replacement.

Condition rating 3 and lower indicate that the bridge shows obvious signs of excess obsolescence.

Four bridge geometry categories analyzed in the section 3 corresponding to each rating number in the form of special classification are used to evaluate a bridge in relation to the level of service. The structures are compared to current standard and current traffic demand for particular type of street (arterial or local). The values of Annual Average Daily Traffic (*AADT*) and magnitude of traffic delays (occasional or significant) is taken into consideration for condition rating. Due to limited space of the paper this classification is omitted here.

After rating of deck geometry, safety features, clearances, and approach road the general rating is provided. The general bridge rating usually is the lowest categories rating and must reflect any safety concerns related to the function of the bridge. Of the 65 bridges analyzed in this investigation and currently located on city streets 27 (41.5%) are reported sufficient and 38 (58.5%) show the signs of functional obsolescence.

Fig. 11 and Table 2 show the percentage of bridge deficiencies by rating number and bridge geometry category. The two most common deficiencies concern underclearances and approach road geometry. There are 33.8% and 27.7% of bridges respectively having condition rating 3 or less. Some structures are functionally obsolete in several categories. Approx 68.4% of the bridges with functional deficiencies have one functional deficiency, 26.3% two and about 5.3% three deficiencies.

The relationship between functional obsolescence categories and bridge's age is shown in Fig. 12. The results show that functional deficiencies decrease as age of bridges also decreases. Older bridges are more likely to be functionally obsolete than newer ones. For example, the proportion of functionally obsolete bridges is above 20% in 15 to 25 years old category, over 60% in 45 to 55 years old category. Fig. 12 also shows that new recent bridges being constructed after 1996 are not deficient in any category.

This condition rating of inspected bridges is considered as a today's condition evaluation and is not used to predict future functional aging of the structure. The surveying of individual bridges subject to functional deficiencies is continuing. The condition ratings help to priority planning of future inspections and maintenance of bridges.

5. Conclusions

1. A survey of 65 city bridges performed within a relatively short period (2–5 years) on their functional

Table 2. Functionally obsolete bridges by geometrical category

	Deck geometry Category I	Safety features Category II	Underclearances Category III	Approach geometry Category IV
Non deficient	54	57	43	47
Functionally obsolete	11 (16.8%)	8 (12.3%)	22 (33.8%)	(27.7%)

performance has revealed that 27 bridges (41.5%) had adequate condition, whereas 38 (58.5%) were showing well-defined or low-marked signs of functional obsolescence. The highest percentage of obsolete bridges is classified in underclearance (33.8%) and approach roadway (27.7%) categories. Moreover, functional deficiencies increase with age. Extensive functional obsolescence is common in many bridges over 25 years old. In most cases the obsolete bridges continue to function, but at levels below contemporary standards. The bridges constructed after 1996 are not deficient in any category.

2. Some functionally deficient bridges were analyzed according to the methodology described in Part I of this paper. Each bridge should be examined individually. Reduced speed of traffic and associated traffic delay was the principal criteria justifying functional obsolescence of these bridges. It was found that due to rapid growth of traffic flows the traffic congestion is a prevalent phenomenon in many city bridges. The traffic congestion leads to longer trip times and additional user costs. For example, the case study of the two-way four lane, 14 m wide and 174 m long with the average ADT = 16 100 vpd bridge connected with approach street circle interchanges showed that traffic congestion causes a delay of 9500 vehicle-hours and 21 150 user-hours each year.

3. Functional surveying of bridge stock to make functional evaluation was the first step in Lithuanian bridge management. Each bridge should be examined individually for deficiencies that could affect the level of service provided to bridge users and excess user costs. Realistic estimation of functional obsolescence of the bridge stock requires detailed knowledge of the current situation based on long-term prediction results. The surveying of individual bridges subject to functional deficiencies is continuing. The results from this research are used for proposals to update current design guidelines and to develop new effective maintenance methods.

References

Brown, J. L. 2002. Demolition: Segmental Bridges Carefully Dismantled, *Civil Engineering* 72(8): 28–29.

Das, P.; Gibbs, M. 2001. Vehicle Collision Loading Criteria for Bridge Piers and Parapets, in *International Conference „Safety, Risk and Reliability – Trends in Engineering“.* March 21-23, 2001, Malta. International Association for Bridge and Structural Engineering: 249–254.

Çalişkanelli, P.; Özuysal, M.; Tanyel, S.; Yayla, N. 2009. Comparison of Different Capacity Models for Traffic Cercles, *Transport* 24(4): 257–264. http://dx.doi.org/10.3846/1648-4142.2009.24.257-264.

Daunoras, J.; Bagdonas, V.; Gargasas, V. 2008. City Transport Monitoring and Routes Optimal Managenet Systems, *Transport* 23(2): 144-149. http://dx.doi.org/10.3846/1648-4142.2008.23.144-149.

Dell'Acqua, G.; Russo, F. 2010. Speed Factors on Low-Volume Roads for Horizontal Curves and Tangents, *The Baltic Journal of Road and Bridge Engineering* 5(2): 89–97. http://dx.doi.org/10.3846/bjrbe.2010.13.

El-Tawil, S.; Severino, E.; Fonseca, P. 2005. Vehicle Collision with Bridge Piers, *Journal of Bridge Engineering* 10(3): 345–353. http://dx.doi.org/10.1061/(ASCE)1084-0702(2005)10:3(345).

Ghose, A. 2009. Strategies for the Management of Bridges for Vehicular Impacts, in *Proc. of the ICE - Structures and Buildings* 162(1): 3–10. http://dx.doi.org/10.1680/stbu.2009.162.1.3.

Horberry, T.; Halliday, M.; Gale, A. G. 2002. Bridge Strike Reduction: Optimising the Design of Markings, *Accident Analysis and Prevention* 34(5): 581–588. http://dx.doi.org/10.1016/S0001-4575(01)00055-0.

Jurevičius, R.; Bogdevičius, M. 2007. Determination of Traffic Flow Parameters in Different Traffic Flow Interaction Cases, *Transport* 22(3): 236–239. http://dx.doi.org/10.1080/16484142.2007.9638131.

Kamaitis, Z. 1997. Vehicle Accidental Impacts on Bridges, *Statyba* [Civil Engineering] 4(12): 20–27.

Kamaitis, Z. 2011. Influence of Functionally Obsolete Bridges on the Efficiency of Road Network. Part I: Obsolescence Characteristics and Assessment, *The Baltic Journal of Road and Bridge Engineering* 7(3): 171–178. http://dx.doi.org/10.3846/bjrbe.2012.24.

Martin, A.; Mitchell, J. 2004. *Measures to Reduce the Frequency of Over-Height Vehicles Striking Bridges.* Final Report PRT079/04, Transport Research Laboratory (UK): 78 p.

Retting, R. A.; Williams, J.; Schwartz, S. I. 2000. Motor Vehicle Craches on Bridges and Countermeasure Opportunities, *Journal of Safety Research* 31(4): 203–210. http://dx.doi.org/10.1016/S0022-4375(00)00037-2.

Trouillet, P. 2001. Truck Impacts on French Toll-Motorways Bridge'S Piers, in *International Conference „Safety, Risk and Reliability – Trends in Engineering“.* March 21-23, 2001, Malta. International Association for Bridge and Structural Engineering: 729–734.

Xin-Zheng, L.; Yan-Sheng, Z.; Jian-Jing, J,; Ai-Zhu, R.; Jing, N. 2007. Nonlinear Finite Element Simulation for the Impact Between Over-High Truck and Bridge-Superstructure, in *Proc. of the 7th International Conference „Shock and Impact Loads on Structures“.* October 17-19, 2007, Beijing, China, 387–394.

Yang, M.; Qiao, P. 2010. Analysis of Cushion Systems for Impact Protection Design of Bridges Against Overheight Vehicle Collision, *International Journal of Impact Engineering* 37(12): 1220–1288. http://dx.doi.org/10.1016/j.ijimpeng.2010.06.007.

Žilionienė, D.; Oginskas, R.; Petkevičius, K. 2010. Research, Analysis and Evaluation of Roundabouts Constructed in Lithuania, *The Baltic Journal of Road and Bridge Engineering* 5(4): 240–245. http://dx.doi.org/10.3846/bjrbe.2010.32.

Received 11 April 2011; accepted 13 June 2011