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## VEHICLE ACCIDENTAL IMPACTS ON BRIDGES

Z. Kamaitis

### 1. Introduction

Highway and railway bridges over roads are subjected to the risk of damages caused by vehicular impact. It seems that the incidents to bridge sub- and superstructures are increasing. The number of collision accidents has been recorded on many sites of Lithuania as well as in other countries involving sometimes a large economic losses. Vehicle collision with railway bridge structures may cause derailment of passing trains leading to severe consequences. However, very little research has been carried out on this subject. A few references [1, 2, 3, 4, 5, 7] dealing with vehicle impact on bridges are known.

The problem of vehicle/bridge collision is closely related to progressively increasing traffic density as well as size and weight of vehicles. Vehicle impact loads under the bridges are not considered in the design of bridge superstructures and piers. Many bridges built more than 20-30 years ago have inadequate circulation clearances causing the safety and circulation problems of old bridges. In addition to bridge damage, vehicle/bridge collisions may result in loss of human lives and serious environment damage.

In Lithuania many bridges over roads are damaged due to substandard headroom and abnormal traffic roads, despite warning circular signs. It seems that the counter-measures actually used in high risk bridges are not effective and sufficient. Thereby it is necessary to analyse the causes of vehicular collisions and to determine which structures are particularly at risk.

The following two main questions have to be considered:

- \* how to determine the value and direction of impact loads as well as the area and location of load application needed to be considered in accidental design situations;
- \* how to assess the collision risk, the causes and consequences of accidents of existing bridges and which necessary safety measures have to be taken.

This paper describes the results of inspections and investigations carried out in Lithuania on bridges damaged by vehicular collision. The objective of this investigation was to study the factors affecting the collision damages of structures and to propose the procedures for assessment of the risk and consequences of bridge failures.

### 2. Vehicle-bridge collision

During the 1985-96 period, a series of impacts by vehicles on highway bridges was recorded. It can be seen in Fig 1 and 2 of some serious accidents in Vilnius regarding vehicle/bridge collisions [5].

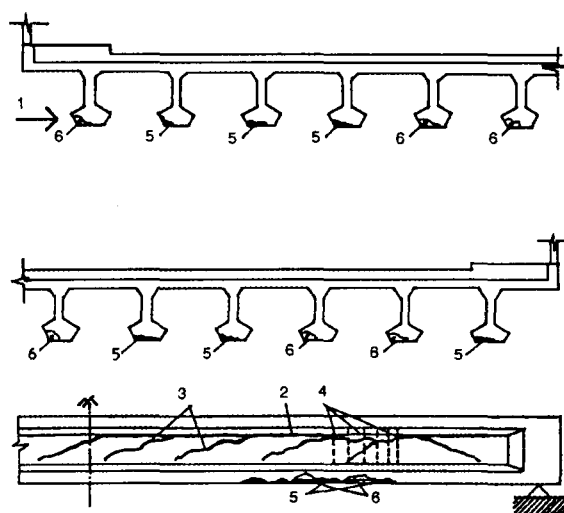


Fig 1. Scheme of fractured span structure of reinforced concrete viaduct: 1 - place of impact; 2 - longitudinal crack (width up to 70 mm); 3 - diagonal cracks (width up to 1 mm); 4 - place of disrapture of stirrups; 5 - spalls of concrete; 6 - spalls of concrete cover

The first example (Fig 1) concerns the viaduct with a simple supported superstructure consists of 18 pretensioned concrete T beams spanning 33 m. The traffic intensity here is one of the highest in Vilnius. An excavator transported on a trailer hit the edge beam of the viaduct. The accident resulted in the spalling of concrete from the bottom flange and formation of a number of diagonal cracks. This damage

was also attributed to shear at the connection between the web and the top slab of the beam, as well as to the rupture of some vertical stirrups. In all beams the spall of concrete with or without an exposure of reinforcing bars is observed.

A similar impact on another reinforced concrete bridge deck spanning 20 m over the street resulted in concrete crushing at the bottom flange of the edge beam and breakage of some stirrups and longitudinal steel bars (Fig 2,a).

The bridges were repaired. Unfortunately, the bridge superstructures were damaged again by transporting excavators whose boom was too high to pass under the bridge. The accidents of such sort continue to occur despite the warning signs on the bridges limiting the maximum vehicle size.

Also, as a result of the vehicle impact, the collapse of a reinforced concrete column of bridge pier (Fig 2,b) and the lateral displacement and considerable deformation of the main beam of the suspension steel footbridge can be mentioned (Fig 2,c).

*a*



*b*



*c*



Fig 2. Collision damage of reinforced concrete edge beam (a) and pier column (b) of highway viaduct, and of main beam of the suspension steel footbridge (c)

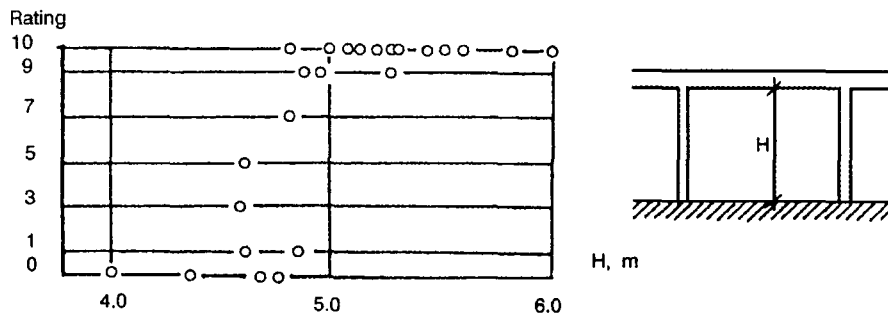


Fig 3. Relationship between intensity of damages of viaduct superstructures and height of highway clearance

In 1996, in Alytus due to a truck loaded with logs collision with railway bridge superstructure the lateral displacement of deck beams observed was of 0.7 m. The risk of derailment of passing trains was very high. The displacement of railway was recorded in time and an accident was avoided.

Fortunately, in the above-mentioned cases no human deaths were involved, but sometimes large economic losses due to repair of structures as well as the interruption of traffic circulation take place. Our investigations show that many bridges over roads and streets in Lithuania are damaged due to impact by tractor trailers or their loads. Most existing bridges do not fulfil the modern requirements to the vertical clearance.

The main consequences of vehicle/bridge collision are:

- \* damage to the bridge (the cost of destroyed parts of the bridge);
- \* damage to vehicles and to goods carried by the vehicle;
- \* injuries and loss of human lives;
- \* repair/replacement costs including cost of transport circulation reorganisation during the bridge repair period;
- \* business and social losses due to disruption of traffic circulation;
- \* damage to the environment (for example, spilling of oil products or other chemicals etc).

A wide range of failures from superficial damage to disaster is possible. With regard to impact load, local and global effects on bridge structures are to be distinguished. The local behaviour refers to influences in the impact zone, the global effects describe the behaviour of individual structural member or the structure as a whole. Criteria used in our investigations for the assessment of bridge collision damages are divided into classes:

- 0 - destruction of structures and dangerous defects (rupture of main reinforcement, crushing of concrete, excessive deflections or displacements of the structure) leading to global failure of structural members and as a result closure of traffic circulation;
- 1 - serious defects (crushing of concrete, severe cracking, excessive deformations or rupture of some reinforcement bars) referring to the global behaviour of the individual structural members or the bridge as a whole;
- 3 - punching failure and excessive spalling of concrete, single cracks, excessive deformations of longitudinal reinforcement bars or stirrups in the zone of impact;
- 5 - excessive spalling of concrete cover in the impact area;
- 7 - local damage of a concrete cover or spalling of concrete edges;
- 9 - small local defects (signs or tracks of mechanical impacts);
- 10 - undamaged.

The relationship between the size of vertical clearance under the bridge and intensity of damages is shown in Fig 3. It can be seen that the intensity of damages is directly proportional to the vertical clearance under the bridges.

### 3. Vehicle impact forces

Bridge design standards give values and combinations for various live and dead loads which have to be considered when evaluating load carrying capacity and serviceability of structures. The special-purpose vehicles, such as crane vehicles, tractor trailers, trucks and others, transporting abnormal or heavy loads, may exceed the standard loads as well as the vertical or horizontal clearances under bridges. New types of vehicles may appear. The impact forces on a bridge during collision depend on such parameters as vehicle

type, size, mass, and speed as well as the circumstances of the accident (eccentricity of impact, size and shape of structures etc). It seems that the amount of reinforcement and the bar spacing play a significant role in reinforced concrete damage resistance. The accident circumstances are usually not known sufficiently well. In case of eccentric impact, for example, a significant part of the collision energy will be consumed in friction and rotating of the vehicle. Thereby, the determination of the impact load on a bridge during the vehicular collision accidents is very complicated.

The impact impulse can be calculated as (Fig 4):

$$S = \int_0^{\tau} F(t) dt = F_m \tau, \quad (1)$$

where  $F(t)$  is impact force.

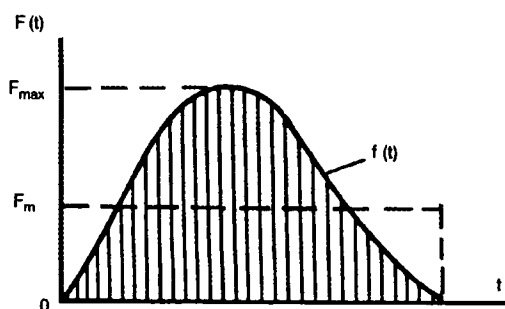


Fig 4. Schedule of impact force

On the other hand, it can be written that

$$\int_0^{\tau} F(t) dt = (m/g)v_0 + (m/g)v, \quad (2)$$

where  $m$  is vehicle mass (kg);  $v_0$  and  $v$  are vehicle speed before and after impact, respectively (m/sec);  $g$  is acceleration of gravity (9.81 m/sec<sup>2</sup>).

Normally the duration of action of the maximum force in vehicle/bridge collision is very brief. Therefore, it can be written from (1) and (2) that average impact force:

$$F_m = m/g\tau v_0(1+v/v_0). \quad (3)$$

For concrete structures (concrete to steel impact)  $v/v_0 = 0.35-0.15$ ; for steel structures (steel to steel impact)  $v/v_0 = 0.6-0.4$ .

The collision impact forces depend on the deformability of both the vehicle and the part of structure directly affected as well as on the direction of impact. The analysis of a vehicle collision accident can also be based on the assumption that kinetic energy will be transformed into plastic deformation of the vehicle as well as structural damage deformation of the bridge

$$1/2(m/g)v^2 = \int_0^{u_1} F_1(u) du + \int_0^{u_2} F_2(u) du. \quad (4)$$

As shown in Fig 5, the right hand side of Eq 4 represents the summation of the two cross-hatched areas. The first term represents the energy dissipation due to vehicle crashing, the second term - the energy dissipation due to local crashing of structure and is taken into account when the force exceeds the force  $F_{02}$  required to produce damage. The energy observed by elastic deformation of vehicle  $u_{02}$  and structure  $u_{02}$  is small and may be neglected.

The plastic deformation of the front end of the car in collision tests (car mass 1500 kg, speed 50-60 km/h) may be assumed to be about 0.4 m [6]. The resulting force can be found:

$$F_{max} = ma, \quad (5)$$

where the average deceleration  $a = v_0^2 / 2 \cdot 0.4 = 1.25v_0^2$ , (m/cek<sup>2</sup>).

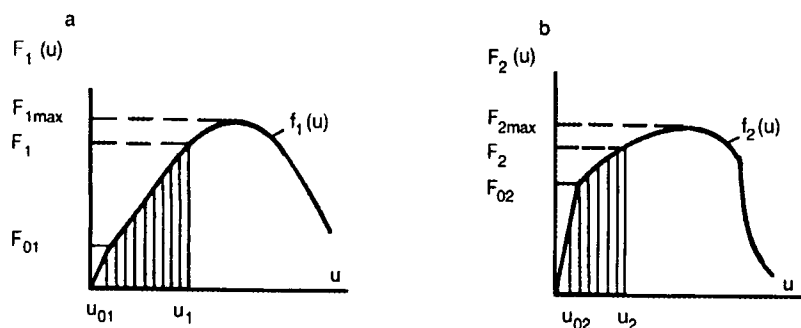


Fig 5. Impact force versus deformation of vehicle (a) and bridge structure (b)

In the floating debris, ice, shipping, and traffic/bridge collision analysis the impact force model was proposed [9]:

$$F(t) = c(mv_0^2 / s), \quad (6)$$

where  $s$  equals the stopping distance, and  $c$  is the factor accounting the variation of bridge stiffness and relative angle of impact.

The real impact loads of vehicles on the bridges can also be calculated from the loads required to deform the structural elements observed in the damaged structures. But it is not easy to do that due to complexity of calculation scheme.

The dynamic effects of moving traffic loads during collision is not considered in many design standards. Ref [7] indicates the magnitude of horizontal force needed for verifying the local strength of the bridge piers (Table). The impact force is applied at the level of 1.5 m from road surface. According to [10], the collision force is 1000 kN in the direction of vehicle travel or 500 kN perpendicular to that direction, acting 1.25 m above the road level. It can be seen that the ratio of transverse impact force to longitudinal force is taken 0.5.

Speed of heavy vehicle (from 15 to 19 t), km/h	Impact force in longitudinal direction, kN	Impact force in lateral direction, kN
90	1000	500
75	800	400
60	500	250

For impact force between the vehicles and a bridge superstructure no data have been found in the literature. Not all vehicle mass is affected on the bridge superstructure. It seems, that impact force depends on the size of the contact area. It can be assumed that the horizontal force is 0.1-0.2 of vehicle collision force on pier.

The dynamic interaction between vehicles and bridge structures is very complicated. The duration of impact loads is so short that the structural member reacts in quite a different manner than in static or repeated loading. The increase in strength of reinforcement and concrete due to the high strain rate, the absorption of vehicle impact energy in rotation and friction as well as plastic displacement of vehicle and bridge structures have to be taken into consideration. The failure of structural member subjected

to local impact can lead to the subsequent collapse of neighbouring structural elements or the bridge as a whole. The collapse can be prevented if the structural system has the ability to redistribute the forces quickly and to sustain the additional stresses.

#### 4. Bridge clearances

The horizontal and vertical clearances under the bridges have to ensure that circulation span is sufficient to provide safe transport passage under normal conditions. In any bridge over the roadway, the higher the superstructure up in the air or the larger the distance between the piers, the greater the cost. There is a constant effort to keep a structure as low as possible. To avoid a high risk of vehicles collision, the clearance of the circulation should be as high and large as can be technically and economically justified.

Horizontal span clearance under the bridge over streets and roads is planned in accordance with traffic density for one- or two-way traffic with one, two or more lanes of circulation. The minimum width of vehicle circulation lane is 2.5 m and that of the railway is about 5.0 m. For a bridge crossing, road or railway, it is thus suggested that the span clearance should be related to the width of way plus a certain distance to bridge piers (reserve zone) providing a free and safe circulation at service speed. It is not difficult to meet these requirements in the design stage of new bridges. But in reconstruction works the widening of circulation lanes (for example, up to 3.5 m for highway roads) sometimes reduce the reserve zone involving increased accident risk.

The vertical clearance in the circulation span of a bridge should be planned to allow the passage of the possible highest vehicle including vertical vehicle movements. According to the international practice, the vertical clearance dimensions in highways should be not less than 4.5 m. In US minimum roadway clearance are defined in the AASHO specifications. The height of clearance should be not less than 4.65 m. Sign bridges should have a clearance of at least 5.4 m. In Swedish bridges the height of clearance have to exceed 4.7 m. Up to 1984 all bridges in Lithuania were designed for 4.5 m high clearance. Later, according to SNiP 2.05.03-84, the vertical clearance for city and I, II, and III category roads was increased up to 5.0 m. It was assumed that this clearance dimension allows the passage of abnormal vehicles as well as installation of trolley lines.

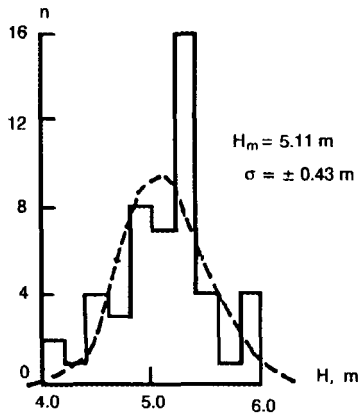


Fig 6. Histogram of headroom distribution of all Vilnius bridges

Data of vertical clearance measurements in all Vilnius bridges over the streets are shown in Fig 6. It can be seen that the scatter in the vertical dimensions is very considerable. Therefore it is clear that the bridges are subjected to different level of collision risk.

### 5. Collision risk

Bridge design standards impose live loads and number of dimensional limits to allow the bridge to support the traffic under adequate conditions of safety. The vehicle characteristics such as weights and dimensions as well as bridge clearance are random variables. It is not possible to predict when or which bridge will be damaged by vehicle collision. But it is possible to determine which bridge is particularly at risk. The collision risk analysis and assessment have to answer to the questions what level of risk is acceptable, how can the risk be controlled or reduced, and at what cost and effort.

Two approaches may be applied to assess the probability of failure of existing structures:

- \* the empirical approach based on the vehicle/bridge accident statistics;
- \* the probability approach based on probability distributions for different factors have to be involved in analysis.

The probability of damage of the bridge structures due to vehicle collision is complicated and is a function of the vehicle type, mass, speed, direction as well as the strength and stiffness characteristics of the bridge structures. The most important factors affecting the risk evaluation of collision are:

- \* type of bridge (highway, pedestrian, railroad);
- \* traffic density and speed under and over the bridge, loading conditions in goods, number of passengers;
- \* geometry and state of traffic route (turns, widths, quality of surfacing);
- \* importance of the bridge to society, business and industry, national defence;
- \* environmental conditions (darkness, fog, rain, snow);
- \* type and geometry of bridge structures;
- \* mechanical failures, accidents and human errors.

Consequences of vehicle/bridge collision accidents are related to damages of vehicles and bridge structures as well as the risk of damages of vehicles or derailment of trains passing the bridge and deaths or injuries of passengers or pedestrians.

The geometrical probability of vehicle / substructure and vehicle/superstructure failure is shown in Fig 7. For a bridge piers the geometrical failure probability is a function of lateral distribution of vehicle

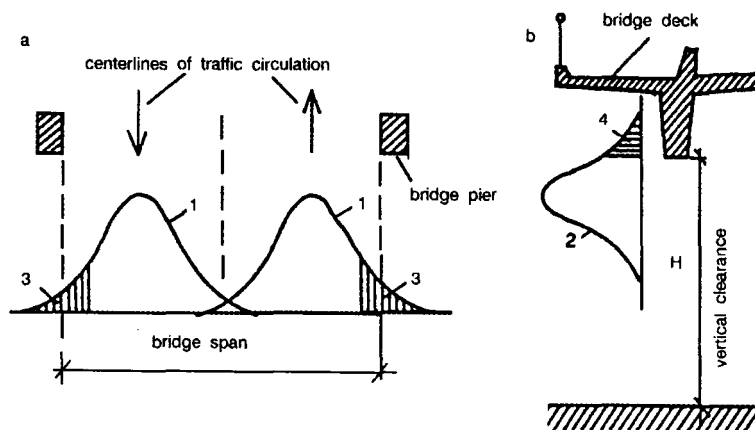


Fig 7. Geometrical probability of collision for piers (a) and deck (b): 1 - vehicle track distribution; 2 - vehicle height distribution; 3 - vehicle/pier collision zone; 4 - vehicle/deck collision zone

tracks and the width of collision zone which is equal to the breadth of vehicle plus breadth of the pier. For bridge deck the collision zone is related to the distribution of height of vehicles and bridge clearance as well as the number of circulation lanes under the bridge.

Geometrical probability of vehicle/bridge collision

$$P(G_b, G_v) = P(G_b) \cdot P(G_v), \quad (7)$$

where  $P(G_b)$  is the geometrical probability related to the actual part of a pier or deck of a bridge;  $P(G_v)$  is the geometrical probability of vehicle dimensions belonging to a certain class (including illegal height vehicles and swinging up effect of moving vehicles).

The lateral distribution of vehicle tracks as well as the distribution of height of clearance and that of vehicles can be approximated with normal distribution. The parameters of distribution may be obtained from direct observations. It is necessary to stress that estimates of failure probability on the basis of actual collisions are difficult due to lack of sufficient data.

The failure probability related to the users (vehicles, trains, passengers, pedestrians) passing the bridge

$$P(P_c, C_e) = P(P_c) \cdot P(C_e), \quad (8)$$

where  $P(P_c)$  is probability of vehicle/bridge collision;  $P(C_e)$  is probability of train, vehicle or pedestrians on a bridge during the impact time.

The most dangerous event will be for railway bridges where due to impact the derailment may occur with serious consequences. On the other hand, the bridges over the same road have to be analysed in different accidental design situations. For example, footbridges are generally much more sensitive to collision forces than road bridges. Failure consequences of railway bridges may involve large loss of lives, environment pollution or significant economic losses for the society. The higher clearances for those bridges have to be envisaged. Vehicle/bridge collision is an accidental design scenario and the reduced level of safety against failure as general is acceptable. Localised damage of structures can be accepted that it will not cause the failure of the whole structure.

In the vehicle/bridge collision risk analysis, the cost assessment due to accident has to be considered. In many cases it is not economically feasible to design and built the bridge with very strict requirements of safety level. The objective is to choose the level of

risk that provides the minimum sum of prevention or protection cost and that of collision accident.

## 6. Prevention measures

Vehicle collision accidents to bridge structures are relatively rare. Therefore the design of a bridge structures to withstand the vehicles impact is not envisaged in many current design codes and specifications.

Collision risk reduction can be achieved by the following specific protective measures:

- \* traffic regulation measures
- \* bridge protection measures
- \* introduction of bridge design codes.

Traffic regulation measures consist of installation of passage limitation signs for maximum vehicle size and speed. Warning circulation signs are provided directly on the bridge structure or at the sides of the road. A series of nightmarks on the sub- and superstructures provides the visual fluorescent message in the dark. Although the drivers probably observe the warning signs, the accidents continue to occur.

The gates located at some distance from a bridge are used as visual and audible warning to drivers. The coloured gates may be constructed of portal frames with horizontal or vertical metal, timber or plastic suspended elements. In modern traffic circulation system the presence of abnormal vehicles is detected by lasers or radars.

The bridge protection system is installed to prevent, redirect or reduce the impact loads on the bridge sub- and superstructures. In high risk bridges, piers can be protected by providing reinforced concrete or metal barrier beams or guard rails. They are erected along the road to separate the roadway from piers or abutments as well as the opposite circulation directions.

The standards normally prescribe the clearance profiles under the structures for highway and railway bridges as function of the class of road or density of road traffic. Special demands for passage should be envisaged on special transporters carrying the abnormal cargoes (containers, engineering plants etc). In high collision risk bridges, the collision actions should be considered for the structural design where appropriate traffic regulation and bridge protection measures are not provided.

The benefits of added protection take the form of reduction of failure probability and of losses re-



sulting from failure. It seems that the cost of protective measures is always less than future losses due to traffic accidents.

## 7. Conclusions

Many existing bridges over roads and streets do not fulfil the requirements of the horizontal and especially vertical clearances and many new bridges sometimes economy does not allow full compliance either. The number of collision accidents has been recorded on many sites of Lithuania as well as in other countries involving sometimes large economic losses due to repair costs as well as indirectly to circulation restrictions.

The circulation conditions in the vicinity of different bridge sites should be studied and the vehicle accident data collected. The new Lithuanian Code "Design of bridges" (being prepared at present) has to prescribe the clearance profiles under the bridges as well as accidental actions arising from vehicle impacts on bridge piers and superstructures.

During the maintenance of existing bridges attention should be paid to collision preventive and protective measures in order to keep the accidental risk at an acceptable level.

## References

1. C. Gledhill, C.J.F.P. Jones. The Repair of Bridges, Damaged by Vehicular Impact // International Conference on Gestion des Ouvrages d'Art. Brussels-Paris: 13-17 April 1981, vol. 1, p. 339-344.
2. Y. Kreps-Heyndriks, M. Callens Repair. Works of a Prestressed Suspension Bridge Damaged by an Accident // International Conference on Gestion des Ouvrages d'Art. Brussels-Paris: 13-17 April 1981, vol. 1, p. 366-370.
3. G.P. Mallett. Protection of Low Bridges. International // Conference on Gestion des Ouvrages d'Art. Brussels-Paris: 13-17 April 1981, vol. 2, p. 603-607.
4. G.P. Mallett. Repair of Concrete Bridges. London: 1994, 194 p.
5. Z. Kamaitis. Condition State and Assessment of Reinforced Concrete Bridges. Vilnius: Technika, 1995, 182 p. (in Lithuanian).
6. W.H. Dilger, A. Ghali. Response of Spun Cast Concrete Poles to Vehicle Impact // PCI Journal, Vol. 31, 1986, p. 62-82.
7. J.A. Calgaro. Project and Construction des Ponts. Paris: LNPC. 1992, 256 p.
8. A. Kerkovius. Repair of Precast Prestressed Bridge Beams using External Prestressing // IABSE Symposium. Extending the Lifespan of Structures, San Francisco: 1995, p. 979-984.
9. T.E. Fenske, C.J. Apelt, A.C. Parola. Debris Forces an Impact on Highway Bridges // IABSE Symposium. Extending the Lifespan of Structures, San Francisco: 1995, p. 1017-1022.
10. Eurocode 1. Part 3: Traffic Loads on Bridges. ENV 1991-3:1995, 130 p.

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## AUTOMOBILIŲ ATSTITIKTINIAI SMŪGIAI Į TILTUS

Z. Kamaitis

### Santrauka

Viadukus dažnai pažeidžia po jais važiuojantis negabaritinis transportas. To priežastis yra nuolat didėjantys transporto priemonių ir jomis vežamų krovinių svoriai ir gabaritai bei nepakankami viadukų konstrukcijų artumo gabaritai. Straipsnyje pateikti konkretūs automobilių netinkamo važiavimo po viadukais pavyzdžiai (1 ir 2 pav.). Sudarytas viadukų konstrukcijų būklės reitingas, naudotas Vilniaus statinių būklei vertinti (3 pav.).

Norint veiksmingai apsaugoti statinius nuo atsitiktinių transpoto priemonių smūgių, reikia:

- nustatyti smūginių apkrovų dydžius bei jų veikimo ruožus;
- įvertinti naudojamų statinių avarių tikimybę.

Įvairiai siūloma vertinti atsitiktinių apkrovų dydžius [(3), (5), (6) formulės, lentelė]. Susidūrimo metu atsiranda kinetinė energija, kurią absorbuoja automobilis ir tilto konstrukcijos [(4) formulė]. Susidūrimo jėga pasiskirsto tarp automobilio ir tilto konstrukcijų atvirkščiai proporcingai jų standžiams.

Tikimybiniais skaičiavimais reikia analizuoti dvi galimas situacijas:

- geometrinę automobilių ir viaduko susidūrimo tikimybę [7 pav., (7) formulė], kuri labai priklauso nuo potiltės gabarito (6 pav.) ir transporto priemonių matmenų;
- tikimybę, kad susidūrimo metu viaduku važiuoja traukinys, yra daug automobilių ar pėsčiųjų [(8) formulė], kurie gali nukentėti avarijos metu.

Tikimybiniais skaičiavimams reikia turėti pakankamai patikimų statistikos duomenų apie transporto priemonių gabaritus, eismo sąlygas, viadukų konstrukcijas.

Atsitiktiniai transporto smūgiai bei viadukų potiltės gabaritai turėtų būti apibrėžti normomis.

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