- introducing new functions to the building (mainly in the ground floor: services, offices, shops etc.),
- installing lifts to provide accessibility for less able-body inhabitants

In most cases listed above examples have influence on building lay-out and very often actions from both groups are undertaken simultaneously.

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Verhoef L. and oth, (Eds), COST C16, Improving the Quality of Existing Urban Building Envelopes; Vol. 2: State of the Art; Vol. 3: The Needs; Vol. 4: Structures; Vol. 5: Facades and Roofs. IOS Press, UT Delft, the Netherlands, 2007.

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INVESTIGATION OF STIFFNESS OF CABLE AND W-FORM ROAD GUARDRAILS

Introduction. The development of motor vehicle transport is obviously a positive point if viewed in terms of social and economic benefits it brings. The penetration rate of motor vehicles is increasing every year and, based on the projections appearing here and there in press, it will only continue to grow. Though viewed within society as a positive trend, this growth of motor vehicle penetration rate, unfortunately, brings about a number of negative factors, too, with the rate of traffic accidents [1–3] standing as the most critical one. Based on the world-wide statistics [1, 2], each year, about 700 thousand people perish and another 20 million get injured in traffic accidents. In Lithuania, the Traffic Police records about 6 thousand road accidents per year [1–4] which appear in the official statistics under any of the following categories: *vehicle striking a pedestrian*; *vehicle striking a bicyclist*; *collision of running vehicles*; *vehicle rollover*; *collision of vehicle with an obstacle*; *vehicle crashing into another standing vehicle*; *other road accidents*.

According to the same statistic data [4], the *collision of vehicle with an obstacle* accounts for about 11 % of all traffic accidents recorded in Lithuania. In this case, the *obstacle* may be represented by a road guardrail, lighting pole, railway switch, tree, gate or any building structure standing close to the road, etc.

One of the means to raise traffic safety is to increase investments into the roads, including the increasing of road surface quality, their maintenance, change of old road guardrails by new ones. The ideal road guardrail is the guardrail with small and equal stiffness along the road guardrail length. Under interaction of motor vehicle with road guardrail its kinetic energy is transformed into potential strain energy of road guardrail and heat; inertial loads getting by passengers during this process do not exceed the allowed standards.

Mainly road guardrails are installed on main roads, made as horizontal band of W-form attached to the low poles from rolled steel (Fig. 1). The distance between low poles is from 1 to 4 m (it depends on the danger degree of road section). The height does not exceed 0,75 m.

On the regional roads mainly cable road guardrails are installed (Fig. 1). The are made in form of two cables (the diameter is up to 20 mm) attached to the massive concrete low poles with the help of damper. The poles are installed at distance from 2 to 3 m (it depends on the danger degree of road section). The defects of these road guardrails are the following: massive concrete low poles, and also additional maintenance to prevent the tearing of cables before the coming of colds it is necessary to weaken them.

a) b) c)

Fig. 1. Main type of road guardrails which installed on Lithuanian roads:
a – W-form; b – cable; c – parapet

On the bridges and viaduct the road guardrails of parapet type in form of rectangular trapezium are mainly installed (Fig. 1).

Requirements to modern road guardrails. Requirements to modern road guardrails there are [5]:

1.During the interaction of motor vehicle with road guardrail, motor vehicle must be left between road guardrail and edge of road carriage-way, otherwise the interaction with other motor vehicle is possible. The width of mentioned zone must be chosen with consideration of possible road guardrail deformation and place of its installation.

2.During the interaction of motor vehicle with road guardrail motor vehicle retardation must be as less as possible that the motor vehicle can return to the carriage-way.

3.Motor vehicle angle of reflection from the road guardrail must not be more than $0{,}62 \cdot \alpha$ (α – angle of interaction, the angle between motor vehicle speed direction and longitudinal axis of road guardrail).

4.During the interaction accelerations of motor vehicle masses centre with in first $0{,}05\,s$ are not to exceed $5 \cdot g$ in traverse and $7 \cdot g$ in longitudinal directions.

5.During the interaction of motor vehicle with road guardrail motor vehicle is not to turn over or to stick in the road guardrail.

6.There is a variety of motor vehicles models and conditions of their interactions with the road guardrails (angle of interaction, speed of movement) and consequently the problem of universal road guardrail is not solved.

7.Road shoulder width behind the road guardrail must not be less than maximum road guardrail deflection.

8.After deformation the road guardrail must prevent motor vehicle movement into dangerous zone.

9.The works on restoration of road guardrail must not prevent safety transport movement.

10. Road guardrails constructions must economical and aesthetic and also steady for temperature, moisture and aggressive materials influence.

11. Road guardrails constructions are valued according to the principal: safety – effectiveness – aesthetics.

Dynamic loads, getting by motor vehicle during the interaction with the road guardrail. Dynamic loads which motor vehicle gets under interaction with the road guardrail are determined during the experiments with the mannequin and with the help of mathematics modelling. During the experiment accelerations of separate motor vehicle parts and mannequins are registered.

The character of acceleration change depends on motor vehicle type, its movement speed and mass, on dynamic properties and on road guardrail. It is possible to distinguish two main phases of collision from diagrams: the first – increasing of loads up to maximum value (active phase) and the second – diminish of loads (passive phase). Consequently, the real diagram of accelerations (loads) may be changed by simplified (Fig. 2). At the end of active phase the displacement of motor vehicle contact area is finished in longitudinal direction, but motor vehicle mass centre still continue to displace both in longitudinal and traverse directions [5].

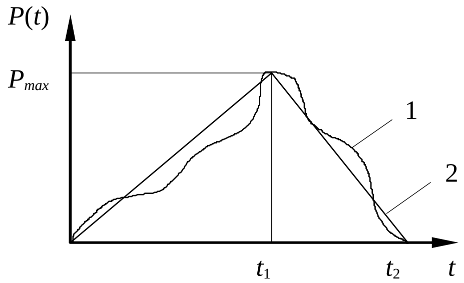

Fig. 2. The dependence of interaction force on time during motor vehicle–road guardrail interaction: 1 – real; 2 – rated

Force impulse during the active phase may be approximated in the following way:

$$S = \int_0^t P(t)dt = \frac{1}{2} \cdot P_{max} \cdot t_1 ,$$

where $P(t)$ – dependence of force of blow on time; P_{max} – maximum force of interaction; t_1 – duration of active phase.

Force impulse perpendicular road guardrail axis during the collision of motor vehicle with road guardrail is equal:

$$S = m \cdot v \cdot sin\alpha ,$$

where m – motor vehicle mass; v – speed of movement; α – angle of interaction (the angle between speed direction of motor vehicle and longitudinal axis of road guardrail).

In this case the maximum force of interaction will be:

$$P_{max} = \frac{2 \cdot m \cdot v \cdot sin\alpha}{t_1} .$$

Mathematical model of road guardrail. The stiffness characteristics of road guardrails were investigated using the Finite Element Method. The mathematical road guardrail model was developed [1, 3, 6].

The road guardrail was modelled using the first-order one-dimensional finite elements (Fig. 3) [1, 3, 6]. At the moment of an impact, the nodes of finite elements change their position within the system of $X - Y - Z$ coordinates (a road guardrail develops deformations). Therefore, while modelling, only the resilience of road guardrail elements as well as soil impact upon the ground-embedded parts of the road guardrail poles were taken into consideration [1].

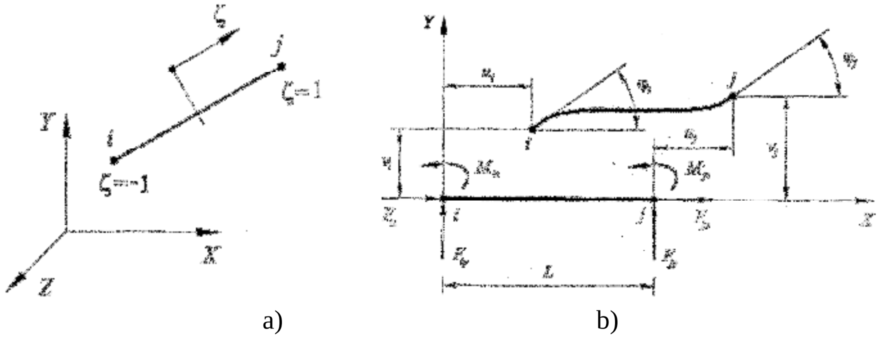

Fig. 3. The first-order one-dimensional finite element: a – the scheme within the system of X–Y–Z coordinates; b – the deformations on X–Y plane

Since a road guardrail is a mechanical system, the system of finite element movement equations was drawn based on the LaGrange second-order equations [1, 3, 6].

Considering the fact that a displacement on a finite element is approximated:

$$\left\{u^{(e)}\right\} = [N] \cdot \left\{q^{(e)}\right\};$$

where $\left\{u^{(e)}\right\}$ – finite element displacement; $[N]$ – finite element shape functions; $\left\{q^{(e)}\right\}$ – vector of finite element generalized displacements,

The following expressions were entered for the finite element: the kinetic energy; the potential energy; the dissipative function; the vector of external forces of impact on the road guardrail finite element.

By entering the above-listed expressions into the LaGrange second-order equation, we obtained the following matrix pattern for the system of finite element movement equations:

$$\left[M^{(e)}\right] \cdot \left\{\ddot{q}^{(e)}\right\} + \left[C^{(e)}\right] \cdot \left\{\dot{q}^{(e)}\right\} + \left[K^{(e)}\right] \cdot \left\{q^{(e)}\right\} = \left\{F^{(e)}\right\};$$

where $\left[M^{(e)}\right]$, $\left[C^{(e)}\right]$, $\left[K^{(e)}\right]$ – matrixes of finite element masses, mechanical energy damping and stiffness; $\left\{\ddot{q}^{(e)}\right\}$, $\left\{\dot{q}^{(e)}\right\}$, $\left\{q^{(e)}\right\}$ – vectors of finite element generalized accelerations, velocities and displacements; $\left\{F^{(e)}\right\}$ – vector of finite element generalized forces.

Further, all systems of finite element movement equations were combined together to form the following general system of road guardrail movement equations:

$$\left[M_{rg}\right] \cdot \left\{\ddot{q}_{rg}\right\} + \left[C_{rg}\right] \cdot \left\{\dot{q}_{rg}\right\} + \left[K_{rg}\right] \cdot \left\{q_{rg}\right\} = \left\{F_{rg}\right\};$$

where $\left[M_{rg}\right]$, $\left[C_{rg}\right]$, $\left[K_{rg}\right]$ – matrixes of road guardrail masses, mechanical energy damping and stiffness; $\left\{\ddot{q}_{rg}\right\}$, $\left\{\dot{q}_{rg}\right\}$, $\left\{q_{rg}\right\}$ – vectors of accelerations, velocities and displacements for all road guardrail nodes; $\left\{F_{rg}\right\}$ – vector of generalized forces of impact on the road guardrail:

$$\left[M_{rg}\right] = \sum_{e=1}^{NE} \left[M^{(e)}\right]; \quad \left[C_{rg}\right] = \sum_{e=1}^{NE} \left[C^{(e)}\right]; \quad \left[K_{rg}\right] = \sum_{e=1}^{NE} \left[K^{(e)}\right]; \quad \left\{F_{rg}\right\} = \sum_{e=1}^{NE} \left\{F^{(e)}\right\};$$

$$\left\{\ddot{q}_{rg}\right\} = \sum_{e=1}^{NE} \left\{\ddot{q}^{(e)}\right\}; \quad \left\{\dot{q}_{rg}\right\} = \sum_{e=1}^{NE} \left\{\dot{q}^{(e)}\right\}; \quad \left\{q_{rg}\right\} = \sum_{e=1}^{NE} \left\{q^{(e)}\right\};$$

where NE – number of finite elements.

The matrixes of finite element masses, mechanical energy damping and stiffness were set considering the performance of finite element deformation on the planes $X-Y$ (Fig. 3) and $X-Z$ as well as the relation between the local and global systems of coordinates [1].

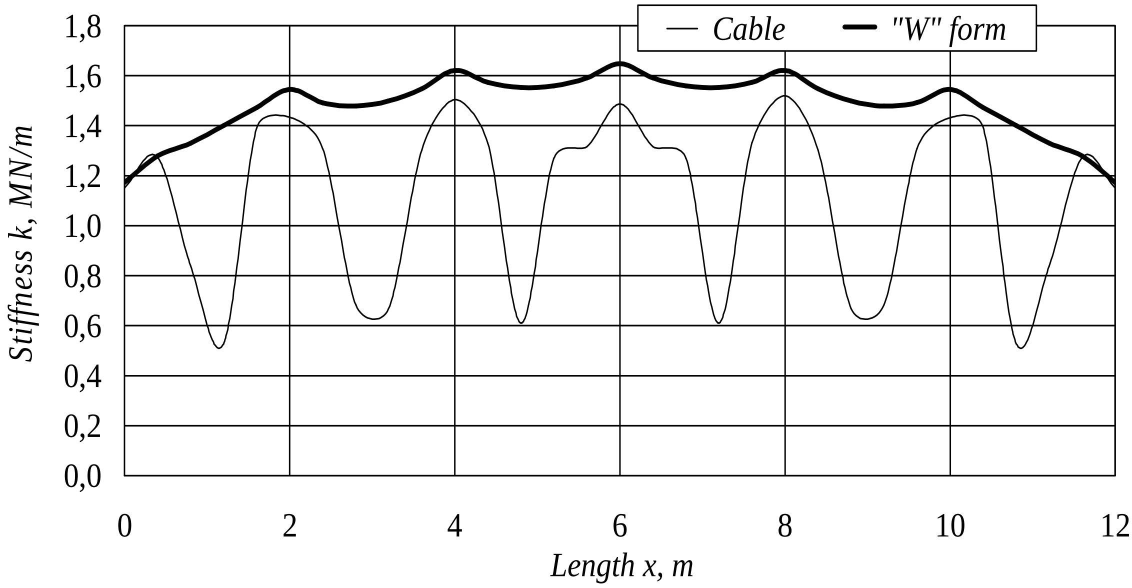

Fig 4. The stiffness of road guardrails (the distance between poles is 2 m)

Computer-run simulation. The computer-run simulation (for the purpose of working out the mathematical model of road guardrail) performed using specially developed *Maple* and *Compaq Visual Fortran Professional* software-based applied programs [7, 8].

Stiffness characteristics of cable road guardrail and W-form road guardrail were calculated by Method of Finite Elements [1, 3, 6].

The road guardrails were divided into finite elements. In each unit cross force (P_{max}) was used and traverse stiffness were calculated [5].

The length of examined road guardrail is 12 m, The distance between poles is 2 m.

Computer-aided test results are showed in Fig. 4.

Conclusions.

1.Designed the mathematical model of road guardrail.

2.The road guardrail modelled based on the first-order one-dimensional finite elements taking into account only the resilience of the road guardrail elements and the impact of soil on the ground-embedded parts of the road guardrail poles.

3.Stiffness of W-form road guardrails along their length is distributed equally, therefore during the interaction of transport vehicle with such a road guardrail, their mechanical trajectory will be the same. It may be explained by the fact that cable road guardrails construction is not perfect because it includes many stiff unprotected poles.

4.In there is a cable road guardrail motor vehicle may be stick between cables and when the blow is more strong transport vehicle may get into dangerous zone.

5.One more defect of cable road guardrail is the following it is necessary to weaken the cables in winter time and tighten them in summer time. This fact in its turn increases the exploitation expenses.

6.The construction of W-form road guardrails is more perfect, the poles are protected from the side of road carriage-way by metal band that's why the stiffness of such a fence along its length is distributed equally.

7.The mathematical model of road guardrail presented may be applied (alone or in combination with other models) for investigating and simulating other traffic events, too.

8.The computer-run simulation (for the purpose of working out the mathematical model of road guardrail) performed using specially developed *Maple* and *Compaq Visual Fortran Professional* software-based applied programs.

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