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Experimental Stress Analysis

Long-time Monitoring of the Bridge Response Caused by Heavy Traffic and Temperature Changes

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Abstract: The paper presents data evaluated from long-time monitoring of the slab-on-girder bridge across the Prague Road Ring near Barrandov. The response caused by heavy duty trucks and temperature changes was monitored during the years 2006 – 2009. The most important evaluated results (heavy duty truck passage density over the bridge, fatigue stress levels, extreme temperature loads) are presented in the paper.

Keywords: Traffic flow, Temperature, Long-time monitoring, Slab-on-girder bridge

1. Introduction

The paper presents most important results of long-time monitoring of the slab-on-girder bridge response caused by heavy duty traffic and by temperature changes. The basic aim of the experiment, which was carried out on three different bridges at the same time (see e.g. [4], [5] and [6]), was to obtain real data for assessment of representativeness of models used for modelling of traffic and temperature loads on road bridges.

In the past twenty years in Czech Republic the intensity of traffic on roads rapidly increased, especially on highways and the first class roads. The composition of traffic flow has changed too. The number of heavy duty trucks has increased substantially and thus the loading of roads and road bridges has increased.

Climatic changes of air temperature and sunshine permanently act on most of the bridges during day and during seasons and they caused time variable temperature development in structural elements, cross sections and points of these structures. The temperature changes cause deformations of a structure. If the deformation is restrained, the additional loading – temperature loading – acts on the structure.

2. Description of the experiment

The investigated bridge is the three span continuous slab-on-girder bridge, which is situated across the four lane Prague Road Ring. The slip lane, which is changing to two lane road on the bridge leads to the street K Barrandovu in Prague. Before opening new part of the Prague Road Ring in September 2010, the heavy duty traffic goes in the south lane of the bridge in the direction Plzeň D5 – Prague Road Ring – Brno D1. It is the three span continuous bridge with spans 17.7 m + 34.5 m + 17.7 m. The bridge is skew with the skewness about 76˚. The load carrying structure of the bridge is composed of four main steel I-shaped girders. The axial

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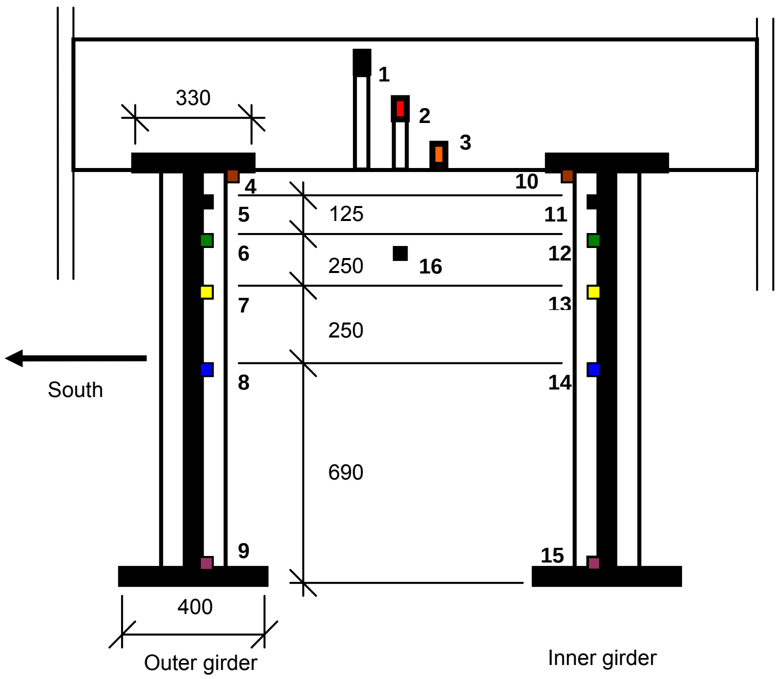

Fig. 1. The schema of the temperature sensors positions on two main bridge girders in the observed cross-section

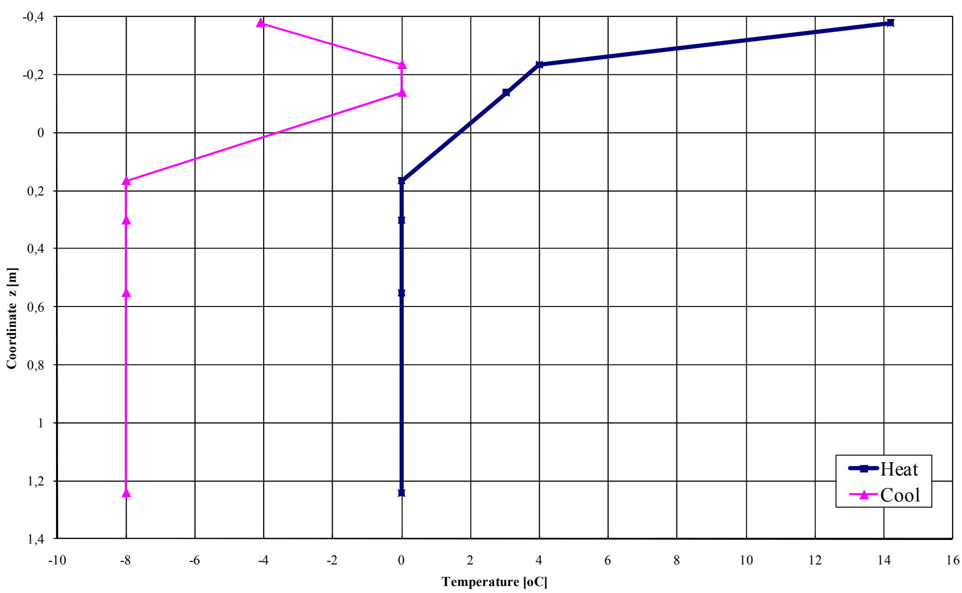

Fig. 2. The temperature component varying non-linearly in the cross section of the investigated bridge according to ČSN EN 1991-1-5 [1]

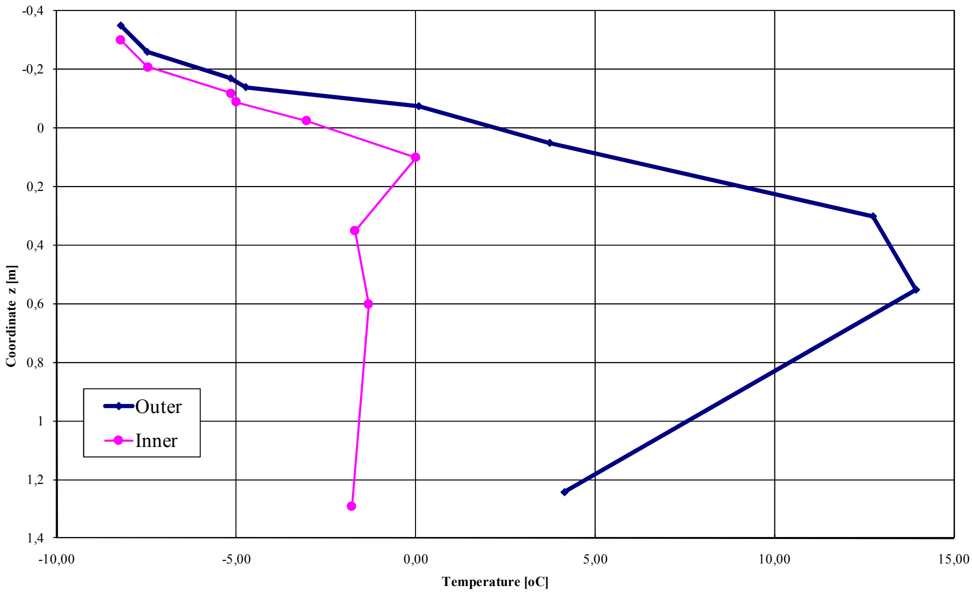

Fig. 3. The measured temperature values in the cross section of the bridge in the time instant, when extreme values of the differential temperature component (cool) was measured on the outer girder - 21.12.2009 11:15

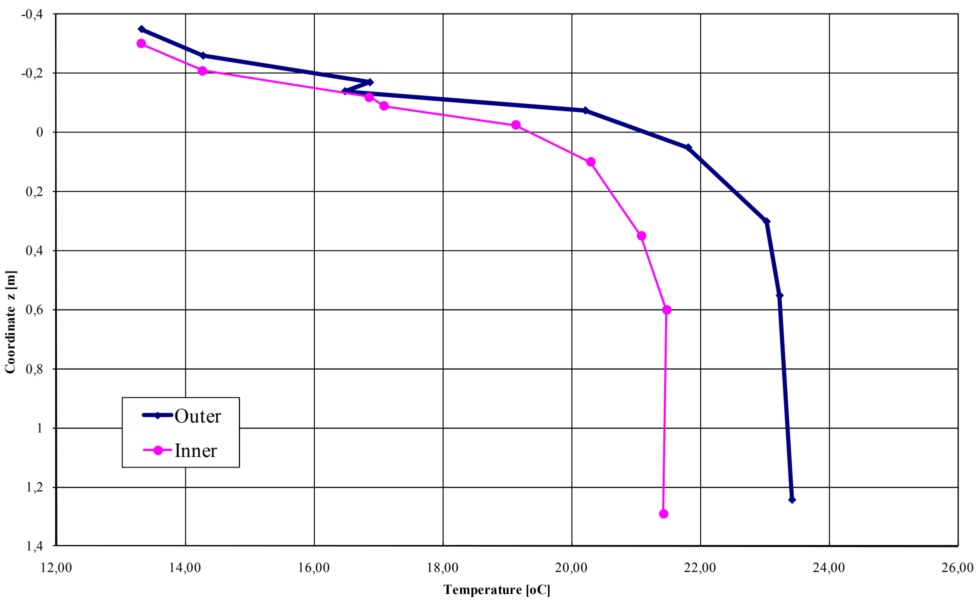

Fig. 4. The measured temperature values in the cross section of the bridge in the time instant, when extreme values of the differential temperature component (cool) was measured on the inner girder - 3.4.2009 14:00

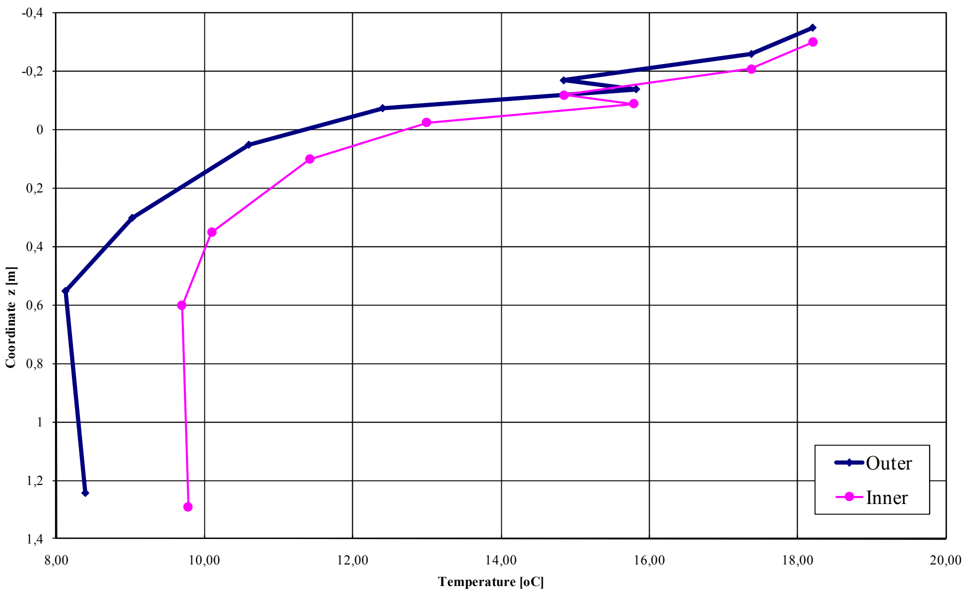

Fig. 5. The measured temperature values in the cross section of the bridge in the time instant, when extreme values of the differential temperature component (heat) was measured on the outer girder - 3.5.2009 4:45

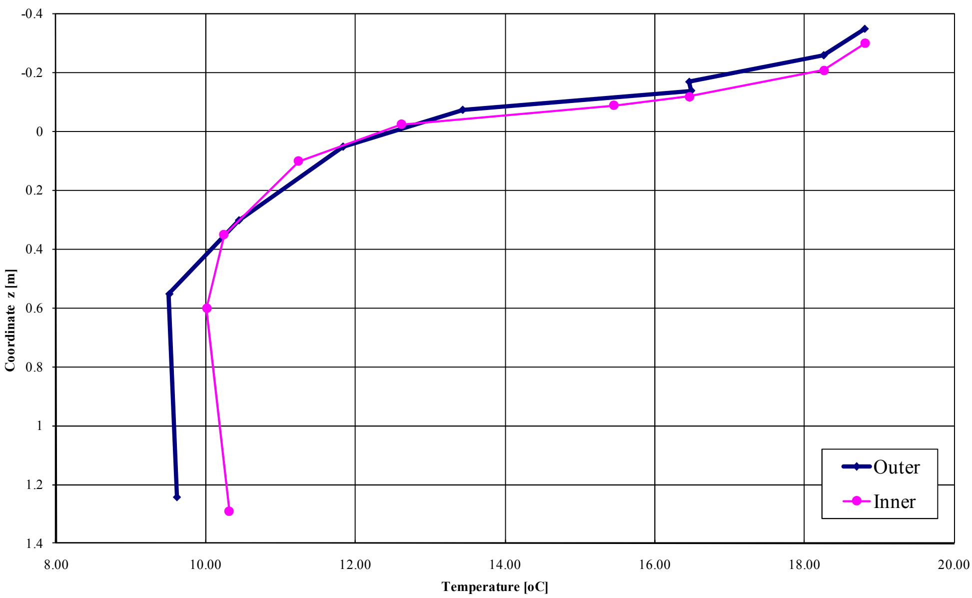

Fig. 6. The measured temperature values in the cross section of the bridge in the time instant, when extreme values of the differential temperature component (heat) was measured on the inner girder - 13. 4. 2009 5:15

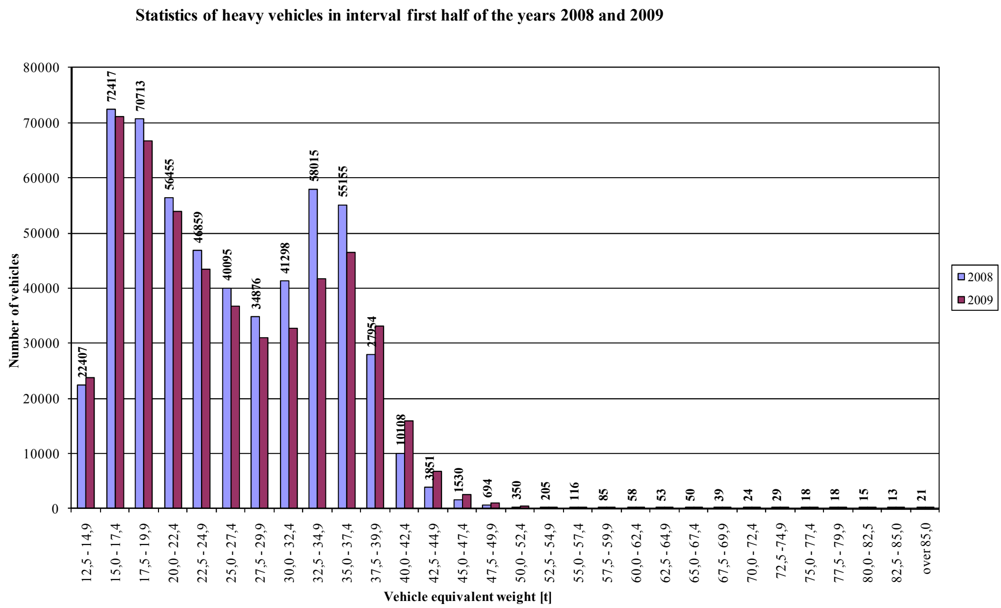

Fig. 7. Statistics of the moving load of the bridge – comparison of the number of heavy vehicles for the first half of the years 2008 and 2009 (the total number of the heavy trucks 543 963 (2008) and 509 200 (2009))

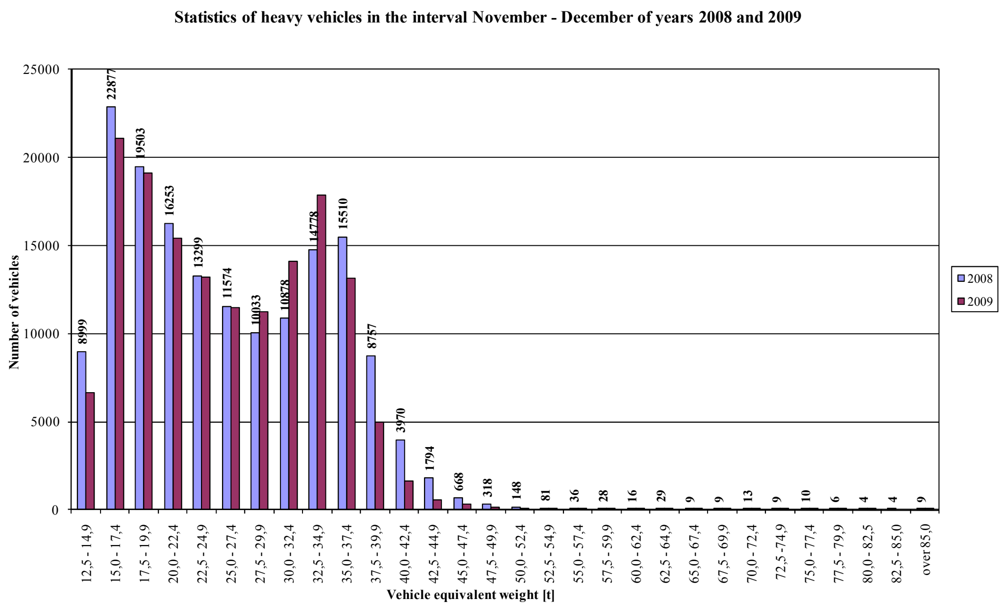

Fig. 8. Statistics of the moving load of the bridge – comparison of the number of heavy vehicles for the interval November - December of the years 2008 and 2009 (the total number of the heavy trucks 159 736 (2008) and 151 384 (2009))

distance of the main girders is 3300 mm. The walls of the steel girders are welded with constant height 1380 mm. The flanges have different thickness along the bridge. The width of the upper flange is 330mm and the thickness is 14 or 18 mm. The width of the lower flange is 400mm and the thickness is in the range from 14 up to 46 mm. The walls of the girders have stiffeners on both sides in varying distances from 1500 up to 2500 mm. The cast-in-place reinforced concrete slab is without transversal inclinations, with constant thickness 240 mm. At the edges, there are short cantilevers of the length 420 mm, resp. 820 mm.

The stress and strain response of two main girders (south outer girder and neighbouring inner girder) and of the reinforced concrete slab was continually measured in the cross section at the middle of the bridge span during the long-time experimental monitoring and temperature was measured simultaneously on the same parts of the bridge.

The measurement line for monitoring of the temperature changes, which was installed on the observed bridge, consisted of the measuring device MS2+ of the company Comet System and of the 16 temperature sensors. The three sensors of type N1ATG8 were inserted in the concrete slab and the twelve sensors of type N1ATG7 were placed on the surface of the steel girders. The air temperature was monitored by means of the N1ATG7 sensor, which hanged freely in space between the observed girders. Positions of the temperature sensors in the observed cross-section of the bridge are visible in Fig. 1.

The measurement line for monitoring of the dynamic response of the bridge was composed from the recording station EMS DV 803 of the firm EMS Miroslav Pohl from Brno in Czech Republic and fourteen strain gauges. The three resistance strain gauges of type 100/120 LY41 HBM were used for measuring the relative deformation of the concrete slab. The measurement of the relative deformations of the steel girders were done using the eleven resistant strain gauges 10/120 LY11 HBM.

In accordance with Eurocode 1 [1] the measured thermal field in the observed bridge cross-section was decomposed in three basic temperature components – a uniform temperature component ΔT_u , a temperature component varying linearly in vertical direction ΔT_{My} and temperature component varying non-linearly ΔT_E. The evaluation procedure with an approximation line smoothing through measured temperature data, which is in detail described in [2], was used. Evaluated year's extreme values of basic components of thermal action and their comparison with corresponding values prescribed in the standard [1] are listed in Tab. 1, where $\Delta T_{My,heat}$ corresponds to the stage of the bridge, when the upper surface is warmer than the bottom surface and where $\Delta T_{My,cool}$ corresponds to the stage of the bridge, when the upper surface is colder than the bottom surface.

Table 1. Comparison of evaluated extreme values of the uniform temperature component ΔT_u and the temperature component varying linearly in vertical direction ΔT_{My} with values prescribed in the standard ČSN EN 1991-1-5

	Outer girder				Inner girder			
	ΔT_u		ΔT_{My}		ΔT_u		ΔT_{My}	
	$T_{e,min}$ [ºC]	$T_{e,max}$ [ºC]	$\Delta T_{M,heat}$ [ºC]	$\Delta T_{M,cool}$ [ºC]	$T_{e,min}$ [ºC]	$T_{e,max}$ [ºC]	$\Delta T_{M,heat}$ [ºC]	$\Delta T_{M,cool}$ [ºC]
Experiment 2006	-3.6	32.4	-18.1	60.2	-3.1	31.4	-8.3	8.3
Experiment 2007	-5.6	**35.6**	-20.1	55.7	-5.4	**34.5**	-9.4	8.3
Experiment 2008	-6.3	31.9	-20.9	60.5	-9.7	30.8	**-10.0**	**8.9**
Experiment 2009	**-12.9**	31.0	**-10.5**	**17.8**	**-12.7**	30.0	-8.9	7.8
ČSN EN 1991-1-5	-27.5	44.5	-15	18	-27.5	44.5	-15	18

One of the objectives of the experiment was monitoring the real load of bridges under its operation. It is possible to estimate weight of the heavy duty trucks passing over the bridge based on the measured response of the bridge. The calibration of measured relative deformations was done based on several passages with vehicle of well-know weight. Because the weight of the vehicles is determined indirectly based on the measured response of the bridge it is called “vehicle equivalent weight”. With respect to the different schemes of the axle positions of the “frequent” heavy duty trucks. the equivalent weight of the common heavy truck is determined with the tolerance + / - 15 %. Estimation of the weight for three-axle trucks (e.g. Tatra 815) is lower than reality. for the lorry-trailer combination with two-axle trailer it is higher than reality and for the lorry-trailer combination with three-axle trailer it is closest to reality. In accordance to the setting of the measuring line. the passages of trucks heavier than 14 t can be evaluated from the results of measuring the dynamic bridge response.

3. Conclusions

From the results shown in Table 1 it results that the uniform temperature components are in the ranges prescribed in the standard ČSN EN 1991-1-5 “Eurocode 1: Actions on structures – Part 1-5: General actions – Thermal Actions”.

The discrepancy between standard values of the temperature component varying non-linearly prescribed in ČSN EN 1991-1-5 (Fig. 2). which correspond to the cooling of the structure (the upper face of a structure is colder than the lower face). and measured temperature values was found out from the analysis of this temperature component (Fig. 3 and 4). From comparison of calculations it results that values of stresses caused by this experimentally obtained temperature component varying non-linearly in the steel part of the cross section significantly exceeded the stresses. which were calculated for loading caused by this temperature component prescribed in the standard ČSN EN 1991-1-5.

The measured differential temperature components (Fig. 5 and 6). which correspond to the warming of the structure (the upper face of a structure is warmer than the lower face). correspond enough to the values prescribed in ČSN EN 1991-1-5 (Fig. 2).

The significant differences between the differential temperature components (cool) of the temperature load of the outer and inner girders were obtained during long-time monitoring (Fig. 3). The outer girder is markedly more loaded than the inner girder. The biggest differences were measured in winter when the sun was low above the horizon and it was directly shining to the wall of the girder.

The amplitude of the relative deformation on the lower flanges caused by heavy duty trucks was usually up to 100 μm/m. the corresponding stress is 21MPa. This value is under the fatigue limit value. the fatigue life of the bridge is not influenced by this loading in the monitored cross section.

In accordance to the setting of the measuring line. the passages of trucks heavier than 14 t can be evaluated from the results of measuring the dynamic bridge response (Fig. 7 and 8). During the experiment in the years 2008 and 2009. the significant response of the bridge caused by trucks of the equivalent weight 90 t was measured about forty times and five times it was response caused by trucks of the equivalent weight more than 100 t.

As it is visible from the Fig. 7 and 8. the traffic intensity in the year 2009 has decreased about 6% in comparison with the intensity in the year 2008 (as the consequence of the world economic crisis) but the number of the trucks heavier than 37.5 t has increased.

Acknowledgements

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