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The influence of longitudinal slope of main road carriage-way on the mass emission from road transport in the atmospheric air

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Summary. Relevance: the issue of the impact of longitudinal slope of the street, as geometrical parameter of carriage-way, on mass emission of pollutants from motor transport is raised. **The tasks of research:** consider the concepts of longitudinal street slopes, discharge, exhaust gas, mass emission, atmospheric air. **The technique of research:** the theoretical technique of analysis for determining the role of longitudinal slope of a carriage-way on the adoption of engineering and planning decision of main roads intersection is implied. **The results of research:** the interdependence of the **mass** emission of pollutants into the atmospheric air from road transport and slope of a carriage-way was established. **Conclusions:** It was established that with increasing slope **mass** emission of pollutants may grow 3...15 times as many.

Key words: longitudinal slope, mass emission, atmospheric air.

GLOSSARY

Atmospheric air – a vital component of the natural environment, which is a mixture of natural gas, which is located outside of residential, industrial and other facilities.

Discharge – intake of pollutants or mixtures of these substances into the atmospheric air.

Exhaust gas (gas that comes out of tailpipes of motor vehicle) – spent working substance in heat engine. This is a product of oxidation and incomplete combustion of hydrocarbon or other fuels. Exhaust gases contain a certain amount (depending on a fuel type of engine and its technical condition) of toxic and harmful components.

Sources of pollutants emissions – the facility where the air contaminant or mixture of these substances come from.

Contaminant – substance of chemical or biological origin that is present or comes into the atmospheric air and can directly or indirectly exert a negative impact on health and the natural environment.

Longitudinal slope – a tangent of inclination angle line of the street to the horizontal plane at the given point.

INTRODUCTION

Longitudinal street slopes, which form a part of transportation planning junction to street and road network of the city, determine the choice of constructive decisions and the geometrical sizes of overpass and with all other factors of placing it in the plan. Depending on the nature of longitudinal profiles of the streets that are compounds of a conjunction, slopes directions and their rates, the question of the vertical planning of junction crossing of main road at the one and different levels is also settled.

Depending on the size and the negative, zero or positive values of the longitudinal slope of street, exit and flyover (when it comes to the junction crossing at different levels), mode of operation of the internal combustion engine vehicle changes and consequently pollutant mass emission in the atmospheric air from the road traffic in general changes too [1, 18].

BASIC MATERIALS SUMMARY

Longitudinal slope is determined due to paragraph 2.27 of DBN V.2.3-5-2001 of "Design standard of streets longitudinal profile according to their categories and the estimated speed of movement should be accepted according to Table 2.8" where the biggest longitudinal slope is accepted from 40 ‰ to 80 ‰, depending on the estimated speed of traffic on the SRN of city streets (Fig. 1) and due to paragraph 2.29 of DBN V.2.3-5-2001 longitudinal slopes of streets should be determined depending on the types of road surfaces by the table 2. 9. According to which slope varies from 5 ‰, and for the reconstruction conditions varies from 4 ‰ to 100 ‰, exceptionally 110 ‰ depending on the type of road surface of the street [3, 4].

Size of longitudinal slope of its individual sections, the radii of vertical curves that connect these areas, high-altitude position of its carriageway relative to the earth's surface is characterized by longitudinal profile of main road.

Longitudinal profile describes the steepness at each part of the street. The natural slopes of the relief may exceed permissible for streets. In this case, the relief is changed by earth excavation.

Selection of a longitudinal profile of the road affects the safety, speed, efficiency of the vehicle and mass emission of pollutants in the atmospheric air. Therefore, technical standards should be kept during the construction of streets and intersectional junctions of main road. These standards set the value of the largest slopes and determine the conditions of profile connection on the fractures. Moreover, all the conditions for a smooth and safe traffic creation with minimum construction cost are taken into account. Street line is divided into the kilometers and the hundred-metre areas called pickets for better orientation.

Longitudinal slope of the street may coincide with the curve in the plan, therefore it has a small radius. In this case, the conditions of the vehicular traffic get more complex. The slope of the carriage-way of street on the curves depends on the

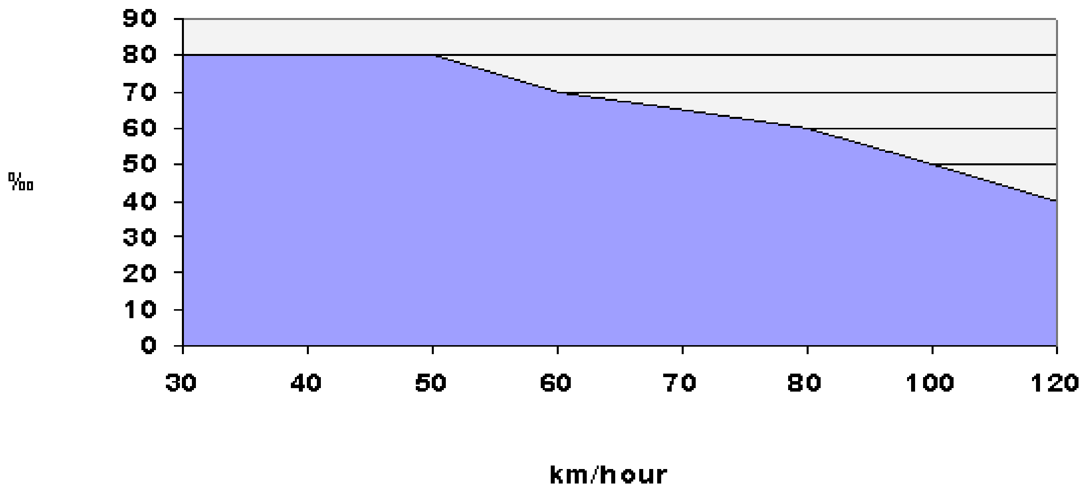

Fig. 1 The relationship between the calculated speed and the largest longitudinal slope in accordance with paragraph 2.27 of DBN V.2.3-5-2001

longitudinal and transversal slopes. The slope of a steep turn favours transport slip, which is slow-moving or brakes on slippery surfaces.

When there are concave longitudinal profiles of main roads that intersect, or at least one concave profile, the construction of intersectional junction of city main roads at different levels would be most appropriate. In this case, the intersection is achieved compactness and reduced length approaches to artificial structures. As a result mileage of turning traffic streams within intersection is reduced. The intersection with the construction of an overpass with the concave longitudinal profiles requires considerable lengths of approaches and increase of the total area of intersection. In this case overpass in terms of architectural and composite solution is usually inappropriate. Concave longitudinal profile of main roads that intersect determine to a large extent the feasibility of using of tunnel solution because the compactness of intersections is provided in so doing and, as a rule, it is also advantageous from technical and economic considerations.

Overpass and tunnel may be created on the flat terrain. In this case, hydrological conditions or technical and economic considerations can be crucial.

In some cases, it is allowed to change the standard value of longitudinal slopes (values higher than recommended for main roads are taken) for reducing the area occupied by the intersection of main roads at different levels and the radius of vertical curves (values less than recommended are taken) can also be changed. So the rational values of longitudinal slopes and the radii of vertical curves are determined by the selection.

After placing exits in plan the validation of longitudinal slopes is made. In the vertical planning of exits the basic condition is to ensure optimal longitudinal slope. On the straight sections the longitudinal slopes of exits must not exceed the maximum allowable values of deviations for main roads that intersect. If it is necessary, longitudinal slopes of exits are allowed to be 10 ‰ larger than the largest allowable slope on main directions of the main roads. Within rounding of exits, starting with a radius of 50 m, the boundary longitudinal slopes should be reduced. With 50 m size of radius boundary value is reduced to 10 ‰, and for every additional reduction by 5 m in the value of the radius of rounding, the boundary value of longitudinal slope should be further reduced by 5 ‰.

Studying existing "methods of calculating mass emissions of pollutants into the atmospheric air from automobile transport" theoretical studies were developed regarding the influence of longitudinal slope of the street on mode of operation of internal combustion engine and as a result on the mass emission of pollutants into the atmospheric air from car and motor stream on the whole.

According to existing methods of calculating of mass emission of pollutants and greenhouse gases into the atmosphere from vehicles dependence g_{ijk} (V) on the slope (S) is set by slope coefficient $C_s = C_{ijk}$ (S) in tabular form for the range -6...0...+ 6%. The product of g_{ijk} (V) * C_s forms a part of the general formula for determining the mass emission. Type of curve C (S) is for the same type of emission ingredients of jk – vehicles (except C_xH_y). The function makes a unity on a smooth road (S = 0%), has a relatively gentle part on slopes and a significant slope on rise of the road. Typical dependence C (S) for diesel vehicles is shown in Fig. 2 [14-17, 19].

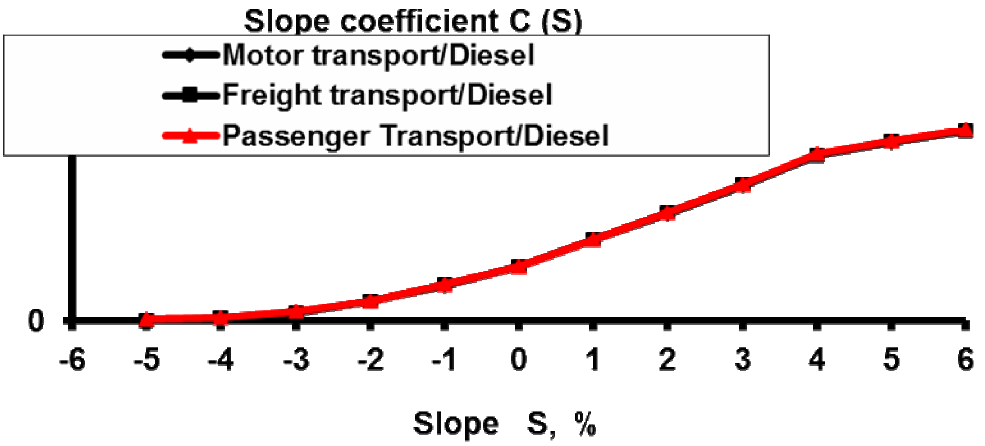

Fig. 2 Typical dependence of specific soot emissions *C* produced by diesel vehicles on the slope *C (S)*

With increasing of the slope from 0 to 5% the emissions of NO_2 and CO can be 3 ... 15 times as many. The increase of emissions of hydrocarbons C_xH_y on slopes is due to the release of undeveloped fuel [5].

The increase of the slope from 0 to 3% causes growth 5...7 times as many maximum single concentration C_xH_y, C, NO_2 with possible exceeding of hygienic norms. $N_{critical}$ = 500 cars/h with a slope of 3% due to the criterion the maximum single boundary permissible concentration (BPC) of NO_2.

Influence on main roadside territory is highly dependent on the slope of the road where NO_2 emissions could increase 6 ... 7 times as many (Fig. 3, Tab. 1) [9-13, 19].

Traffic intensity in two directions (two lanes), when there is no excess of BPC. ms at the distance of 7,5...30,0 m from the curb.

Table 1. Dependence of traffic intensity of transport stream on traffic conditions and longitudinal slope of the roadway

Vehicle traffic terms	Safe traffic intensity, units / hour	
	slope 0%	slope of 3%
Zone before lights	125...500	75...300
Free traffic between intersections	250...1000	125...500
Free traffic on overpass	2000...10000	

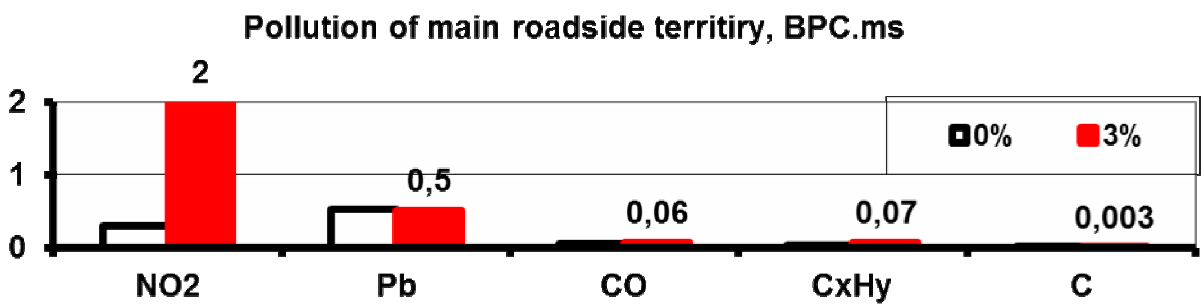

Fig. 3 Maximum single (MS) concentration of emission in 30 meters from the curb of the roadway when there is a traffic of 1000 cars/h on a smooth road (0%) and slope (3%)

Pollution of the roadside territory from the multilevel interchanges is due to these factors: the level of traffic intensity; change in speed limits and consequently change in specific emission at different speeds; the rise of one of the main streams on overpass; slope at the expense of the difference of heights 6...7 m between directions; over mileage of the left-turning streams [1-2, 6-8].

Specific emissions of pollutants into the atmospheric air are used for calculation of emissions of pollutants from motor vehicles from consumption of one ton of fuel and influence coefficient of the technical state of vehicles on them, according to the State Statistics Service Procedures. Calculation of air pollutants from fuel use from motor transports is made due to the formula (1):

$$B_{jikm} = M_{ikm} \cdot G_{jik} \cdot K_{jik}, \quad (1)$$

where: B_{jikm} – amount of j-th pollutant from i-th consumed fuel of k-th type of group of m-th vehicle of business entity; M_{ikm} – amount of i-th consumed fuel of k-th type of group of m-th vehicle of business entity; G_{jik} – j-th specific emissions of pollutant from consumption of i-th fuel of k-th type by group of motor vehicles of business entity; K_{jik} – coefficient of the technical state influence on specific emissions of pollutant (except lead) from the use of i-th fuel type of k-th group of vehicles.

The proposed "Model of dependence of the mass emission from road transport on geometrical parameters of road junction at different levels, such as slope and radius of curves in the plan," is compared with methodology currently in force in accordance with the order №452, 13.11.2008. "On approval of the methodology of the pollutants emission and greenhouse gases calculation into the atmosphere from vehicles "[State Statistics Service of Ukraine, 2008] intended for the calculation of statistical data (tons/year) for the country on the whole, using software" EOL ".

Due to the proposed model of dependence of the mass emission from road transport on geometrical parameters of road junctions at different levels, such as slope and radius of curves in plan, maximum single mass emission of M_{ijk} i-th substance from j-th vehicles type with k-th engine type from the one planar source D is determined in "rush-hour" using the formula (2):

$$M_{ijk} = \frac{N_0 \cdot N_{jk} \cdot g_{ijk}(V_{jk}) \cdot T_{jk}(V_{jk}) \cdot C_s \cdot C_f \cdot C_T}{3600}, \quad (2)$$

where: M_{ijk} – mass emission of i-th substance from j-th type with k-th engine type in "rush-hour", g/*s*, N_0 – the total number of vehicles in one direction, natural units/"rush-hour", N_{jk} – jk-share vehicles in the flow, particle NO, g_{ijk} – specific emission of i-th substance from jk-vehicles, g/s, $g_{ijk}(V_{jk})$ – *gijk* dependence of the current speed *Vjk*, g/s, $T_{jk}(V_{jk})$ – the duration of motor operation of a jk-vehicle in "rush-hour" at a fixed Vjk, s, C_s – coefficient of influence of the road slope, C_f – coefficient of impact resistance of the movement, C_T – coefficient of technical state of vehicles.

The total number of vehicles in one direction N_O (natural units/"rush-hour") is determined separately for each source *D*. In formulae N_O is only in physical units (natural units/"rush-hour"). *gijk (Vjk)* dependence is submitted in tabular form for the range 0...90 km / h. *Vjk (t)* may be different for D_1... D_m sources. *Tjk (Vjk)* of one car during "rush-hour" at a fixed *Vjk* is calculated separately for each *D* sources with different modes of motion. Coefficients C_s and C_f are specific to each *D* source as slope and road surface may vary. Coefficient of influence of the technical state of vehicles and its control, the average age of the fleet C_T are determined in the complex circuit of city transport (CCT). For example, C_T = 1 to 2005, and thereafter C_T = 0,689 are taken for Kyiv [19-22].

We apply the proposed model to optimize the choice of the longitudinal slope of intersectional junction elements of the main road at different levels in terms of traffic interchange at the intersection of bulvard Druzhby Narodiv and Naddnipryanskoho shose in Pecherskuy rayon in Kyiv using mass dependence of pollutant emissions from longitudinal slope coefficient of each individual source. We expect a decrease in pollutants mass into the atmosphere from road transport through optimal ratios of the longitudinal slope. We get the following results on the total mass of pollutants in the air in concordance with methodology in force according to the order №452, 13.11.2008. "On approving the methodology for determining of pollutants and greenhouse gases emissions into the atmospheric air from vehicles" [State Statistics Service of Ukraine, 2008] intended for determination of statistic data (tons/year) for the country on the whole, along with using the software "EOL" and according to the proposed model of dependence of mass emission from road transport on geometrical parameters of main road intersection at different levels, such as slope and radius curves in plan (Tab. 2).

Table 2. Comparing the results of calculations of pollutants mass into the atmospheric air

Ingredients	Mark.	EOL	Model	Difference
		g/s	g/s	%
Nitrogen dioxide	NO_2	0,8431	0,84008	0,35
Carbon monoxide	CO	5,7384	5,71494	0,41
Hydrocarbons	C_{12} - C_{19}	0,8086	0,8058	0,35
Total		7,3901	7,36082	

CONCLUSIONS

1. Vertical planning of main road intersectional junction at different levels depending on the nature of longitudinal profiles, slopes directions and their rates.
2. Longitudinal slope of the streets are taken mainly by 2.27 and 2.29 paragraphs of DBN V.2.3-5-2001 depending on the type of street category and road surface.
3. Longitudinal slope of the street affects the operation of the internal combustion engine of the vehicle and as a result the pollutants mass in the atmospheric air from stream of the vehicles in general.
4. With increasing slope from 0 to 5% the emissions of NO_2 and CO can grow 3...15 times as many. The increase of emissions of hydrocarbons C_xH_y on slopes is due to the release of undeveloped fuel.
5. Influence on the main roadside territory is highly dependent on the slope of the road, where emissions could increase NO_2 6…7 times as many.
6. The proposed "model of the dependence of mass emission from road transport on geometrical parameters of intersection of main roads at different levels, such as slope and radius of curves" when applying it for traffic interchange at the intersection of bulvard Druzhby Narodiv and Naddnipryanskoho shose in Pecherskuy rayon in Kyiv yielded results, such as the decline in the pollutants mass of NO_2, CO and C_{12}-C_{19} into the atmospheric air from road transport through optimal longitudinal slope coefficients corresponding to 0,35, 0,41 and 0,35% respectively. This makes it possible to assert that only the optimization of longitudinal slope rates of elements of main road intersectional junction provides reducing pollutants emissions into the atmospheric air from vehicles. Even if the rate of reduction of mass emission is small not only when it comes to one main road intersectional junction, but also when it is a matter of the entire city road network, the effect will be much more considerable.

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ВЛИЯНИЕ ПРОДОЛЬНОГО УКЛОНА ПРОЕЗЖЕЙ ЧАСТИ МАГИСТРАЛИ НА МАССУ ВЫБРОСОВ ОТ АВТО-МОБИЛЬНОГО ТРАНСПОРТА В АТМОСФЕРУ

Аннотация. Рассмотрены вопросы влияния продольного уклона улицы, эстакады и съездов узла пересечения магистрали в разных уровнях на режим работы двигателя внутреннего сгорания и как следствие массы выбросов загрязняющих веществ в атмосферный воздух. Отмечено, что продольный уклон улицы влияет на режим работы двигателя внутреннего сгорания автомобиля и как следствие на массу выбросов загрязняющих веществ в атмосферный воздух от автомобильного потока в целом.

Ключевые слова: продольный уклон, массы выбросов, атмосферный воздух.