NOISE POLLUTION FROM ROUNDABOUT TRAFFIC IN THE OUTER ENVIRONMENT OF BUILT-UP AREAS OF TOWNS

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Summary: This article describes the positive environmental impacts of roundabouts on their surroundings, particularly in terms of noise pollution. Main purpose of the article is to present the objectification of impact of reconstructing the intersections to roundabouts in urban areas of the Slovak Republic and the Czech Republic.

Key words: environmental impacts, roundabouts, noise pollution, built-up areas

1. INTRODUCTION

This article describes the objectified environmental impacts of roundabouts on their surroundings, particularly in terms of noise pollution. The results of this objectification were found in the workplace of the author, especially in the framework of research projects [1] to [3]. The article builds on author's previous works in the field of objectifying the noise pollution changes caused by reconstruction of intersections to roundabouts in the built-up areas of the town Michalovce [4], [5]. Michalovce town has decided to accede to presented reconstructions primarily in order to increase traffic fluency. In addition to this primary effect, the reconstructions had a secondary effect of significant reduction of accident rate and noise pollution in the vicinity of junction.

Apart from the results from the town Michalovce, the article presents the results of objectified noise pollution from towns Bojnice, Považská Bystrica a Havířov.

2. BASIC DEFINITIONS AND DESCRIPTORS

Act no. 549/2007 Coll. [6], and also the literature [7], [8] list the following explanations of terms related to the issue described.

Noise is every disturbing, obtrusive, unpleasant, undesired, inadequate or harmful sound.

Interim effective value of physical quantity is the value of this quantity determined by the equation

$$u_\tau = \left[\frac{1}{\tau} \int_{-\infty}^{t_o} [u(t)]^2 \cdot e^{(t-t_o)/\tau} dt \right]^{1/2} \qquad (1)$$

where: $u(t)$ is the time function of physical quantity

$e^{(t-t_o)/\tau}$ is exponential time weighting function

τ is the time constant

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t is the continuous time

t_o is the time of observation or value reading

Sound pressure is a continuous effective value of the sound pressure time function $p(t)$ determined by the equation (1).

Sound pressure level; continuous sound pressure level is value determined by the equation

$$L = 10 \cdot \log\left(p / p_o\right)^2 \tag{2}$$

where: p is the sound pressure [Pa]

p_o is the reference sound pressure $p_o = 2.10^{-5}$ Pa

Level of A sound is a level with frequency weighting A. L_A [dB] is a continuous sound pressure level according to (2), which is corrected by the frequency weighting function A, given by the Slovak Technical Standard [9].

Equivalent A noise level L_{Aeq} [dB] is the quantity determined by the equation

$$L_{Aeq} = 10 \cdot \log \frac{1}{T} \int_{t_1}^{t_2} \left[\frac{p_A(t)}{p_o} \right]^2 \cdot dt \tag{3}$$

where: $p_{A(t)}$ is the time function of pressure sound weighted by frequency weighting function A,

T is the integration interval, $T = t_2 - t_1$ [s]

p_o is the reference sound pressure $p_o = 2.10^{-5}$ Pa

Frequency band is the field of frequencies bounded by a lower limit frequency f_d and upper limit frequency f_h; characterized by the centre frequency f_s, for which applies

$$f_s = \left(f_d \cdot f_h\right)^{1/2} \tag{4}$$

If $f_h = 2 \cdot f_d$, frequency band is octave,

$f_h = 2^{1/3} \cdot f_d$, frequency band is one-third octane.

Reference time interval for day is from 6am until 6 pm (12 hrs), for evening from 6pm until 10pm (4 hrs) and for night from 10pm until 6am (8 hrs).

Determining quantity is a physical quantity which characterises the noise and is used for evaluation of unfavourable impacts of noise in terms of public health.

Protected Area is an internal or external environment in which people are staying permanently or repeatedly and for which the limits defining the parameters of noise, infra sound and vibrations are set (such as protected residential room, protected territory).

External environment is protected outdoor area outside the buildings, where people reside due to resting, recreational, therapeutic or other than professional reasons, and in front of external walls of apartment buildings, schools, healthcare facilities and other buildings requiring a quiet environment.

Objectification is the determination of assessed value of operating quantity.

Sound barrier is an equipment to reduce the noise, preventing the direct penetration of the sound from the road traffic.

Roundabout - junction, at which the road traffic is directed by one-way road around the centre island. Has the diameter of 25 m < D = 45 m; does not allow vehicles interweaving on

the circulating roadway between the entrances and exits. According to the method of passing, it may be:

- without traffic access on to the centre island,
- with limited traffic access on to the centre island [10].

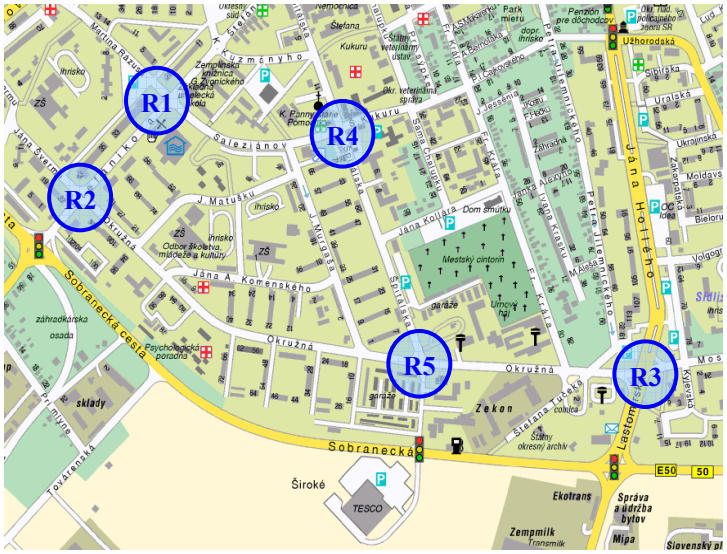
Capacity - capacity offered by roundabouts - permeability determined by the number of vehicles that can travel through the roundabout within a certain time [10].

3. RECONSTRUCTION OF INTERSECTIONS TO ROUNDABOUTS IN THE TOWN MICHALOVCE

3.1. Localization of roundabouts

Localization of service roundabouts in the built-up area of the town Michalovce is presented in Fig.1. Following roundabouts were recently built or designed in the town Michalovce:

- Štefánikova street – Saleziánov street – Rázusa street (in Fig.1 identified as R1),
- Štefánikova street – Okružná street – Jána Švermu street (R2),
- Jána Hollého street – Moskovská – street Okružná street (R3),
- Špitálska street – Saleziánov – Š. Kukuru street (R4),
- Špitálska street – Okružná street (R5).



Source: Author

Fig. 1 - Localization of reconstructed intersections in the town of Michalovce

3.2. Basic roundabout design information

Roundabouts were proposed with the outer diameter D=31 m, entrances were resolved as one-lane 5,5 m wide. This created preconditions for the necessity to reduce the speed at the entrance into the junction while minimizing the junction area. During the implementation of the roundabouts, the existing footpaths were redirected towards pedestrian's crossings

provided in the middle of each entrance and exit branch. The pavement wearing course, as well as the surface of footpaths, was constructed from asphalt bound materials.

Source: Author

Fig. 2 - Junction of streets Štefánikova – Saleziánov – Martina Rázusa
before and after the reconstruction to roundabout

The conducted traffic and noise monitoring [11] to [14], in terms of evaluating the noise pollution at individual junctions before and after reconstruction, identified the following relevant facts.

- **R1** - 29. 5. 2006 from 1100 until 1200 pm
  - total amount of vehicles entering the junction .....1 091 veh/hr,
  - number of trucks and buses (NA).....27 veh/hr,
  - NA [%].....2,5 %.
- **R1** - 12. 3. 2007 from 1030 until 1130 am,
  - total amount of vehicles entering the junction .....1 006 veh/hr,
  - NA [%].....1,6 %.

Source: Author

Fig. 3 - Intersection of streets Štefánikova – Okružná – Jána Švermu
before and after the reconstruction to roundabout

- **R2** - 29. 5. 2006 from 1230 until 1330 pm,
  - total amount of vehicles entering the junction .....1 235 veh/hr,
  - NA [%].....2,8 %.
- **R2** - 12. 3. 2007 from 1300 until 1400 am,

- total amount of vehicles entering the junction .....1 156 veh/hr,
- NA [%].....2,6 %.

Source: Author

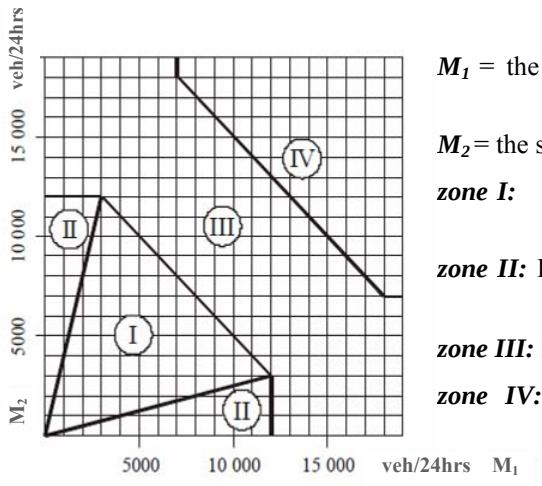
Fig. 4 - Junction of streets Jána Hollého –Moskovská – Okružná, before and after the reconstruction to roundabout

- **R3** - 12. 3. 2007 from 1130 until 1230 am,
  - total amount of vehicles entering the intersection .....885 veh/hr,
  - NA [%].....2,6 %.

Among the presented traffic volumes at R-1 and R-2, the differences of up to 8% were found. This created a successful basis for fair comparison of noise pollution before and after the reconstruction of intersections.

3.3. Capacities of roundabouts

At the time of increasing traffic volume, the nodal points - intersections are becoming the limiting factor of capacity of urban road systems. Technological Regulation TP 04/2004 [10] provides the following estimate of roundabouts' capacities (R) – Fig.5



M_1 = the sum of average intensities of 2 entrances with the heaviest traffic (veh/24hrs)

M_2 = the sum of average intensities of remaining entrances (veh/24hrs)

zone I: R can be proposed without the proof of its capacity, there are favourable conditions for congestion;

zone II: R can be proposed without the proof of its capacity, there are adverse traffic conditions;

zone III: R can be proposed with the proof of its capacity;

zone IV: in this zone the simple one-lane roundabout cannot be proposed.

Source: Author

Fig. 5 - Capacity estimate of roundabout with one-lane entrance, exit and circulating roadway

In relation to the capacities of junctions with management principle "priority from the right" in [15] it is stated that this type is suitable for low traffic load up to 600 to 800 veh / hr

as the sum of all 4 junction's arms. According to Mr Bartoš [16] one-lane circulating roadway roundabout can usually take up to 2000 to 2500 veh/hr, however maximum of 2700 veh/hr (ie app 34 000 veh/24hrs). Actual values of roundabout capacity possibilities depend mainly on:

- distribution of intensities into different traffic streams,
- composition of the traffic stream,
- junction geometric arrangement,
- intensity of crossing pedestrians.

The author agrees with the following opinion of Mr Bartoš. The roundabout is not self redeemable. Inappropriate use of roundabout leads to formation of queues at the roundabout entrance,and the area is usually clogged up for long minutes during the traffic peak time.

3.4. Objectification of the impact of intersections reconstruction to roundabouts

Specific measurements of A sound levels L_A with automatic evaluation of equivalent levels of A sound L_{Aeq} [dB] were conducted by sound analyser NOR-121 accuracy Class 0 (Fig.6). Sound analyser was prior to each set of measurements calibrated by microphone calibrator NORSONIC N-1251 accuracy Class 1. Applied measuring string of noise emissions and pollution has separate verification for:

- own sound level meter,
- measuring microphone,
- one-third-octave filters,
- acoustic calibrator.

Source: Author

Fig. 6 - Measuring system NOR-121 [14]

Measurements were carried out in accordance with the relevant provisions of the corresponding standards [17] to [19]. During the measurements, particularly the following standardization requirements have been observed:

- sound-level meter meets the requirements of accuracy Class 0 or 1,
- sound-level meter allows automatic evaluation of equivalent noise levels,

- microphones meet the required scale,
- microphone and sound-level meter were calibrated at specified intervals by the State Examining,
- during measurements, the microphone was primarily placed on the tripod and covered to protect it from dust and wind. – Fig.7
- during measurements the people were prevented from getting close to the microphone,
- measurement was carried out at appropriate atmospheric conditions (wind up to 5 m/s at 3 to 11 meters above the ground, no rain and snowfall, temperature over 5 °C).

In terms of conducted measurements of equivalent noise levels, before and after the reconstruction of intersections to roundabouts, the results were objectified according to Table 1. and 2 Fig. 7 to 10.

Tab. 1 - L_{Aeq} from intersection traffic of streets Štefánikova – Saleziánov – Rázusa (R-1)

Noise levels from road traffic [dB] – intersection, 29. 5. 2006					
Time	$L_{Aeq,15min}$	$L_{peak,15min}$	**Time**	$L_{Aeq,15min}$	$L_{peak,15min}$
11^{00} to 11^{15}	59.5	90.4	11^{30} to 11^{45}	61.1	93.6
11^{15} to 11^{30}	61.1	94.4	11^{45} to 12^{00}	59.8	91.6
Equivalent noise level $L_{Aeq,1h}$=60,4 dB					
Noise levels from road traffic [dB] – roundabout, 12. 3. 2007					
Time	$L_{Aeq,15min}$	$L_{peak,15min}$	**Time**	$L_{Aeq,15min}$	$L_{peak,15min}$
10^{30} to 10^{45}	58.6	93.9	11^{00} to 11^{15}	58.7	94.1
10^{45} to 11^{00}	58.3	95.4			
Equivalent noise level $L_{Aeq,45min}$=58,5 dB					

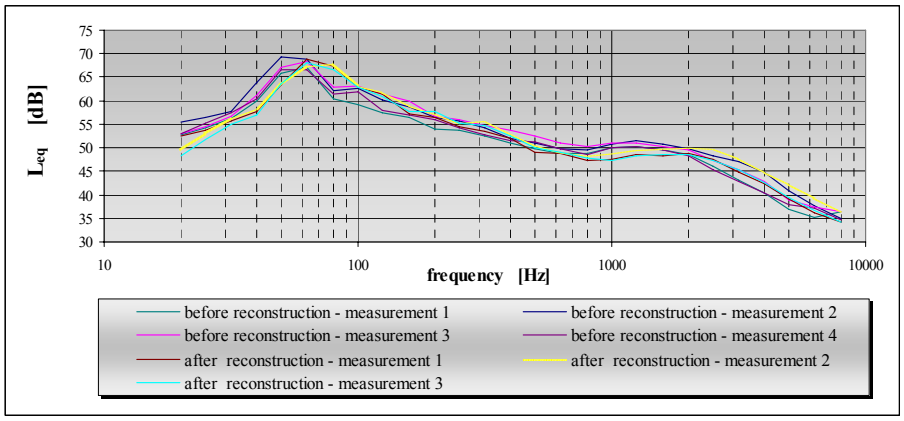
Source: Author

Tab. 2 - L_{Aeq} from intersection traffic of streets Štefánikova – Okružná – Jána Švermu

Noise levels from road traffic [dB] – intersection, 29. 5. 2006					
Time	$L_{Aeq,15min}$	$L_{peak,15min}$	**Time**	$L_{Aeq,15min}$	$L_{peak,15min}$
12^{30} to 12^{45}	63.7	106.1	13^{00} to 13^{15}	60.0	94.0
12^{45} to 13^{00}	60.0	94.1	13^{15} to 13^{30}	61.0	96.2
Equivalent noise level $L_{Aeq,1h}$=61,5 dB					
Noise levels from road traffic [dB] – roundabout, 12. 3. 2007					
Time	$L_{Aeq,15min}$	$L_{peak,15min}$	**Time**	$L_{Aeq,15min}$	$L_{peak,15min}$
13^{30} to 13^{15}	58.9	93.9	13^{30} to 13^{45}	58.5	94.1
13^{15} to 13^{30}	59.5	95.4			
Equivalent noise level $L_{Aeq,45min}$=59,0 dB					

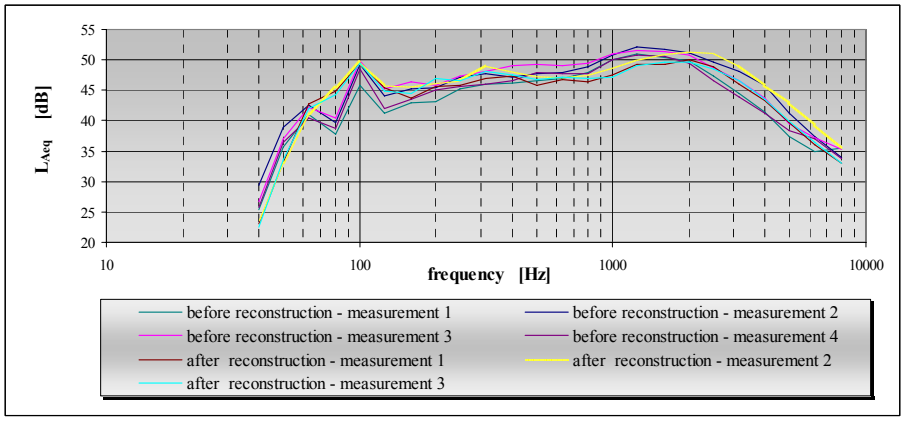
Source: Author

The conducted noise pollution measurements have found that ***implementation of roundabouts has reduced the noise level on average by 2,2 dB.***



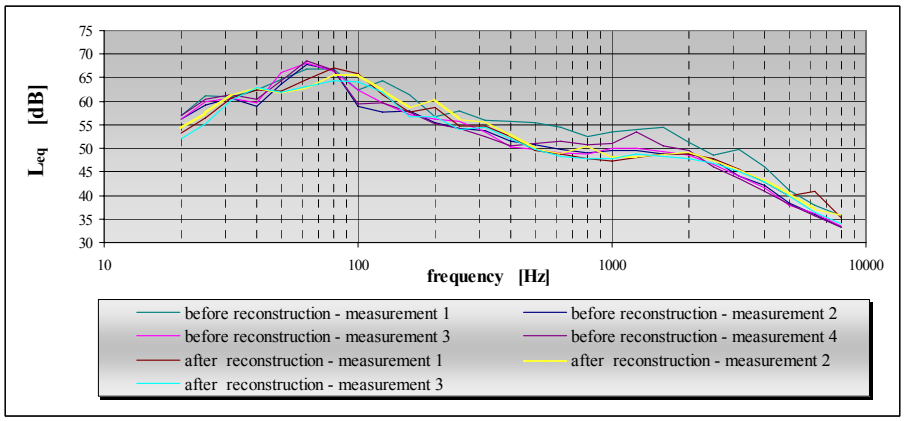
Source: Author

Fig. 7 - Noise levels L_{eq} from intersection traffic of streets Štefánikova – Saleziánov – Rázusa (R1)



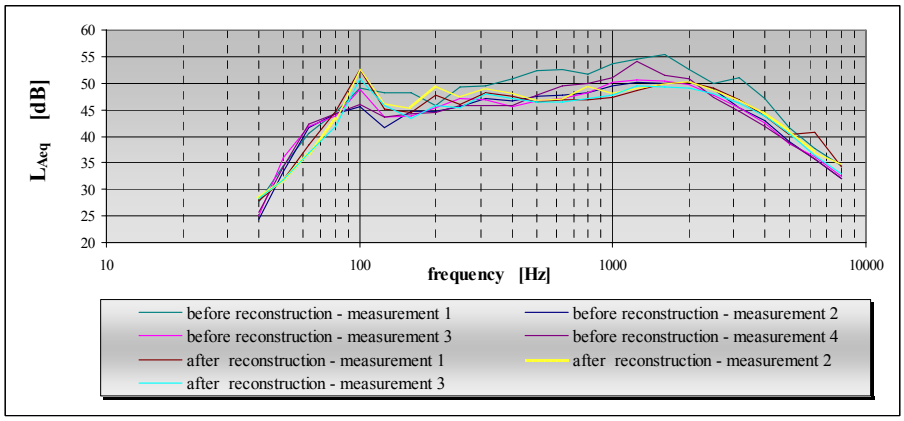
Source: Author

Fig. 8 - Equivalent A noise levels L_{Aeq} from intersection traffic of streets Štefánikova – Saleziánov – Rázusa (R1)



Source: Author

Fig. 9 - Noise levels L_{eq} from intersection traffic of streets Štefánikova – Okružná – Jána Švermu (R2)



Source: Author

Fig. 10 - Equivalent A noise levels L_{Aeq} from intersection traffic of streets Štefánikova – Okružná – Jána Švermu (R2)

4. RECONSTRUCTION OF INTERSECTION TO ROUNDABOUT IN THE TOWN BOJNICE

4.1. Objectification of noise pollution in the vicinity of intersection

During monitoring the noise pollution from traffic at intersection Opatovska road in the town Bojnice were objectified equivalent noise levels at measuring station 1 (MS 1) – Fig.11 and MS 2 (Fig.12) day 29. 5. 2008 before intersection reconstruction [20]. At MS 1 and MS2 were objectified noise levels according to Table 3 and Fig. 14 and 15.

Source: Author

Fig. 11 - Localization of MS 1

Source: Author

Fig. 12 - Localization of MS 2

Tab. 3 - Equivalent noise levels $L_{Aeq,Ti}$ in the vicinity of intersection in Bojnice – 29.5.2008

Noise levels from road traffic in the vicinity of bypass I/64 [dB]					
Time	$L_{Aeq,Ti}$	$L_{peak,Ti}$	**Time**	$L_{Aeq,Ti}$	$L_{peak,Ti}$
Okrajová street in Bojnice – MS 1					
9^{40} to 10^{00}	***67.9***	96.0			
Okrajová street in Bojnice – MS 2					
10^{00} to 10^{15}	63.7	98.3	10^{30} to 10^{45}	63.6	94.3
10^{15} to 10^{30}	63.2	95.0	10^{45} to 11^{00}	65.9	108.0
$L_{R,Aeq}$ **= 64,2 dB**					

Source: Author

4.2. Objectification of noise pollution in the vicinity of the roundabout

7. 2. 2009 after reconstruction to roundabout (Fig.13) the noise levels measured at MS1 and MS2 are according to Table 4 and Fig.14 and 15.

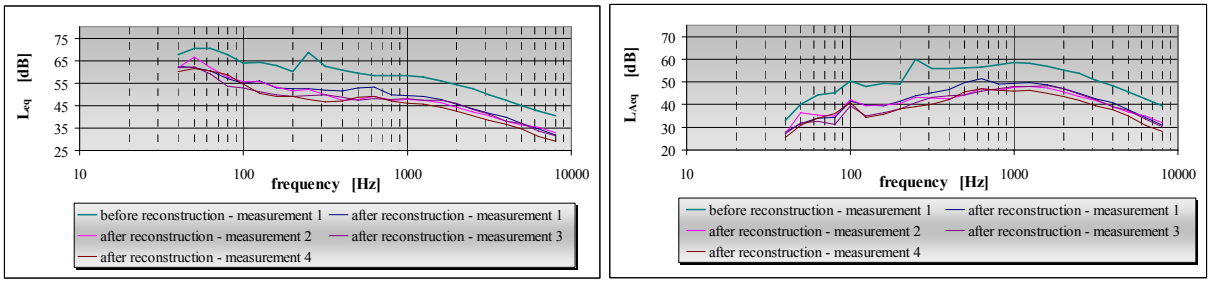
Source: Author

Fig. 13 - Roundabout in Bojnice and MS1 (left down) and MS2 (right down)

Tab. 4 - Equivalent noise levels $L_{Aeq,Ti}$ at the vicinity of the roundabout in Bojnice – 7.2.2009

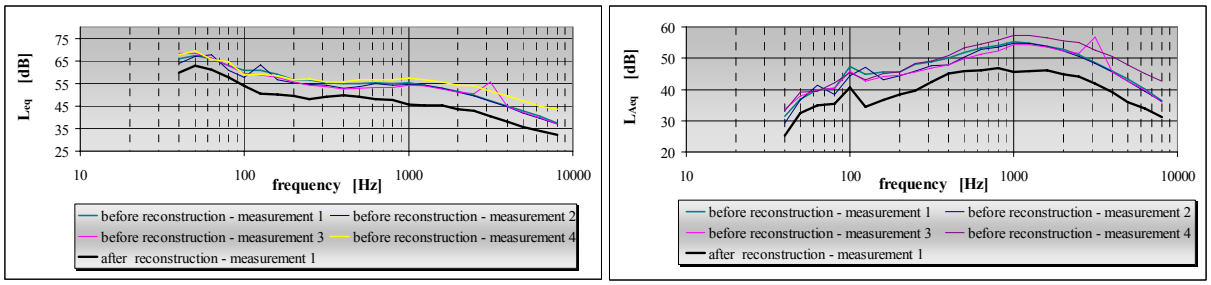
Noise levels from road traffic in the vicinity of the bypass I/64 [dB]					
Time	$L_{Aeq,Ti}$	$L_{peak,Ti}$	**Time**	$L_{Aeq,Ti}$	$L_{peak,Ti}$
Okrajová street in Bojnice – MS 1					
9^{47} to 9^{52}	59.2	89.5	9^{59} to 10^{04}	57.0	88.4
9^{52} to 9^{57}	56.9	88.4	10^{04} to 10^{11}	55.6	87.9
$L_{Aeq,24min}$=57,4					
Okrajová street in Bojnice – MS 2					
10^{00} to 10^{15}	***56.2***	93.5			

Source: Author



Source: Author

Fig. 14 - *Leq* and L_{Aeq} from intersection traffic at Bojnice (MS-1)



Source: Author

Fig. 15 - *Leq* and L_{Aeq} from intersection traffic at Bojnice (MS-2)

Even when taking into account the doubled traffic intensity on 29.5.2008 in relation to 7.2.2009 an ***average reduction*** was objectified in the direct vicinity of the roundabout at the level ***6 dB***. Also according to local citizens' statements, there has been a significant reduction of noise pollution in the vicinity of the roundabout.

5. RECONSTRUCTION OF INTERSECTION TO ROUNDABOUT IN THE TOWN HAVÍŘOV

In 2007 and 2008, in the town Havířov, the intersection of the first class road A11 with the third class roads (streets Na Záguří, Padlých hrdinů) was reconstructed.

Road A 11 from Hradec Králové through Opava, Ostrava, Havířov and further towards Český Těšín, Jablunkov, Čadcu all the way to Žilina was and still is so frequent that entering this road from side roads was considerably difficult [21].

Source: Author

Fig. 16 - Original intersection in the town Havířov

In [22] it is stated that an ***average reduction*** of noise pollution ***resulting from intersection reconstruction*** was objectified by direct measurements of noise levels at level ***4,8 dB.***

Source: [23]

Fig. 17 - View of reconstructed roundabout in the town Havířov [23]

6. RECONSTRUCTION OF INTERSECTION TO ROUNDABOUT IN THE TOWN POVAŽKÁ BYSTRICA

During the Motorway Construction Project D1 Sverepec – Vrtižer, Lot 1 Sverepec – Považská Bystrica, as an induced investment, the intersection (Fig.18) of streets Jánska and Kuzmányho was reconstructed to roundabout (Fig.19).

The results of measured equivalent and maximum noise levels during monitored time intervals are listed in table 5.

Source: [24]

Fig. 18 - Original intersection of streets Kuzmányho and Lánska

Tab. 5 - Equivalent noise levels $L_{Aeq,Ti}$ at R – 18.3.2009, Kuzmányho street 8/907

Noise levels from road traffic of I/59 [dB]					
Time	$L_{Aeq,Ti}$	$L_{peak,Ti}$	**Time**	$L_{Aeq,Ti}$	$L_{peak,Ti}$
16^{08} to 16^{14}	65.7	96.7	16^{33} to 16^{38}	63.8	90.5
16^{14} to 16^{19}	64.0	88.1	16^{40} to 16^{47}	75.3**	109.4
16^{19} to 16^{20}	65.4**	98.5	16^{47} to 16^{53}	65.0	85.8
16^{21} to 16^{26}	64.9	98.4	16^{53} to 16^{58}	66.0	92.2
16^{27} to 16^{33}	63.6	88.4			
* *vehicle horn* ** *ambulance passing by with the siren turned on*					
The resulting equivalent noise level from 16^{08} to 16^{58}h $L_{Aeq,50min}$ = 68,1 dB					
The resulting equivalent noise level omitting measurements * and ** $L_{Aeq,40min}$ = 64,8 dB					
1hr converted traffic volume in both directions ..... 1 586 veh/hr, N=2%					

Source: Author

Source: Author

Fig. 19 - Views of the roundabout at intersection of streets Kuzmányho and Lánska in Považská Bystrica

Based on the measurements it can be stated that the ***reconstruction of intersecting streets Kuzmányho and Jánska to roundabout has resulted in*** a ***reduction of noise pollution by 4 dB.***

7. CONCLUSION

The possibility of noise protection near the grade junction is very limited. To reduce noise pollution from intersection traffic it is virtually impossible to use:

- equipment to reduce noise from road traffic [8] - because of the need to ensure sight distances and traffic safety,

- „low-noise pavement surfaces“ in terms of Slovakia it is mainly by drainage asphalt pavement [25], due to accelerating and decelerating powers and due to turning of trucks [26].

Conducted noise pollution measurements, before and after reconstruction of intersections to roundabouts, objectified the average reduction of noise pollution to external environment in their vicinity at level 4 dB. Above average reduction in theory corresponds with:

- decrease of traffic intensities from 1000 to 400 veh/hr,
- the use of „low-noise" pavement – in our conditions, drainage asphalt pavement,
- absorption by sound barrier 3m high, 400m long, located 50m from the nearest lane 1.5 m above the Terezin.

Specific value of the reduction is apart from changing the characteristics of traffic stream limited by the conditions of pavement wearing course prior to reconstruction [3], [27], by the quality of roundabout new pavement [28], [29] and by the quality of crossing vehicles [30]. It is not author's ambition to present roundabouts as a nostrum for all traffic and environmental problems of built-up areas of towns, but his attempt was to point out objectified positive effects of listed reconstructions under the specific traffic and construction conditions.

8. ACKNOWLEDGEMENTS

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