International Journal of Occupational Safety and Ergonomics (*JOSE*) 2007, Vol. 13, No. 4, 399–408

Wrocław's Motorway Ring-Road—Noise Protection

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The 35.4-km stretch of the A8 motorway, i.e., Wrocław's motorway ring-road (WMRR), passes through the north-west part of the city of Wrocław and 4 neighbouring districts. Analyses have shown that WMRR will be a source of noise in the environment, which may adversely affect large areas. Normative environmental protection acts mandate taking all the necessary technical and organizational measures to reduce noise generated by the operation of WMRR in order to comply with the acoustic environment quality standards. The paper presents the research methodology adopted for assessing noise impact and designing acoustic barriers, and proposed designs of acoustic barriers which take into account the acoustic requirements, technical limitations, urban development, and architectural conditions.

road noise protection   acoustic barriers

1. INTRODUCTION

Because of heavy traffic and speed, noise generated by newly-built motorways adversely affects large areas. Current normative environmental protection acts stipulate that all necessary technical and organizational measures should be undertaken to meet acoustic environment quality standards in the vicinity of new roads. The stretch of the A8 motorway currently being designed, it is called Wrocław's motorway ring-road (WMRR), crosses the south-western part of the city of Wrocław and the neighbouring districts. Because of the local residents' protests, 10 years elapsed between the first plans and the time the location of the A8 toll motorway in the Lower Silesian Province (województwo dolnośląskie) was finally decided on. In the meantime there was a substantial increase in road traffic; the use of land also changed. An assessment of the environmental impact made for WMRR showed that several housing estates and villages were within the range of excessive road noise [1]. Because of the required noise reduction, it is only by building noise barriers that it will be possible to meet the standards of the quality of acoustic environment in the areas legally protected against noise.

2. DESCRIPTION OF WMRR

Ultimately WMRR is to be part of the A8 motorway. All of WMRR will follow a new route crossing the north-western part of Wrocław (Figure 1) [2, 3]. The project's main objective is to direct transit traffic away from Wrocław's road network. At the current stage in the development of the motorway network in Poland, WMRR constitutes a bypass of Wrocław for the existing national road No. 8. WMRR, which is currently being designed, has an overall length of 34.4 km and includes a 26.76-km stretch of motorway A8 and two link roads to the existing national road No. 8, i.e., a south, 2.4-km link and a north, 6.2-km link. WMRR is to include 8 two-level junctions that will divide it into sections with different traffic

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conditions, 13 viaducts and 4 bridges, including a 17.42-km crossing over the Oder river. WMRR is to have the following parameters [3, 4]:

- three traffic lanes in each direction; traffic lane width: 3.75 m;
- predicted traffic volume: 20 000–26 000 vehicles per 24 hrs in the years 2010–2015 and 50 000–63 000 vehicles per 24 hrs in 2025–2030;
- percentage of heavy-class vehicles: $p_c = 27\%$;
- traffic speed: $V_o/V_c = 130/90$ km/hr; and
- road surface type: stone mastic asphalt.

The nearest existing housing developments within the city boundaries are located 40–70 m

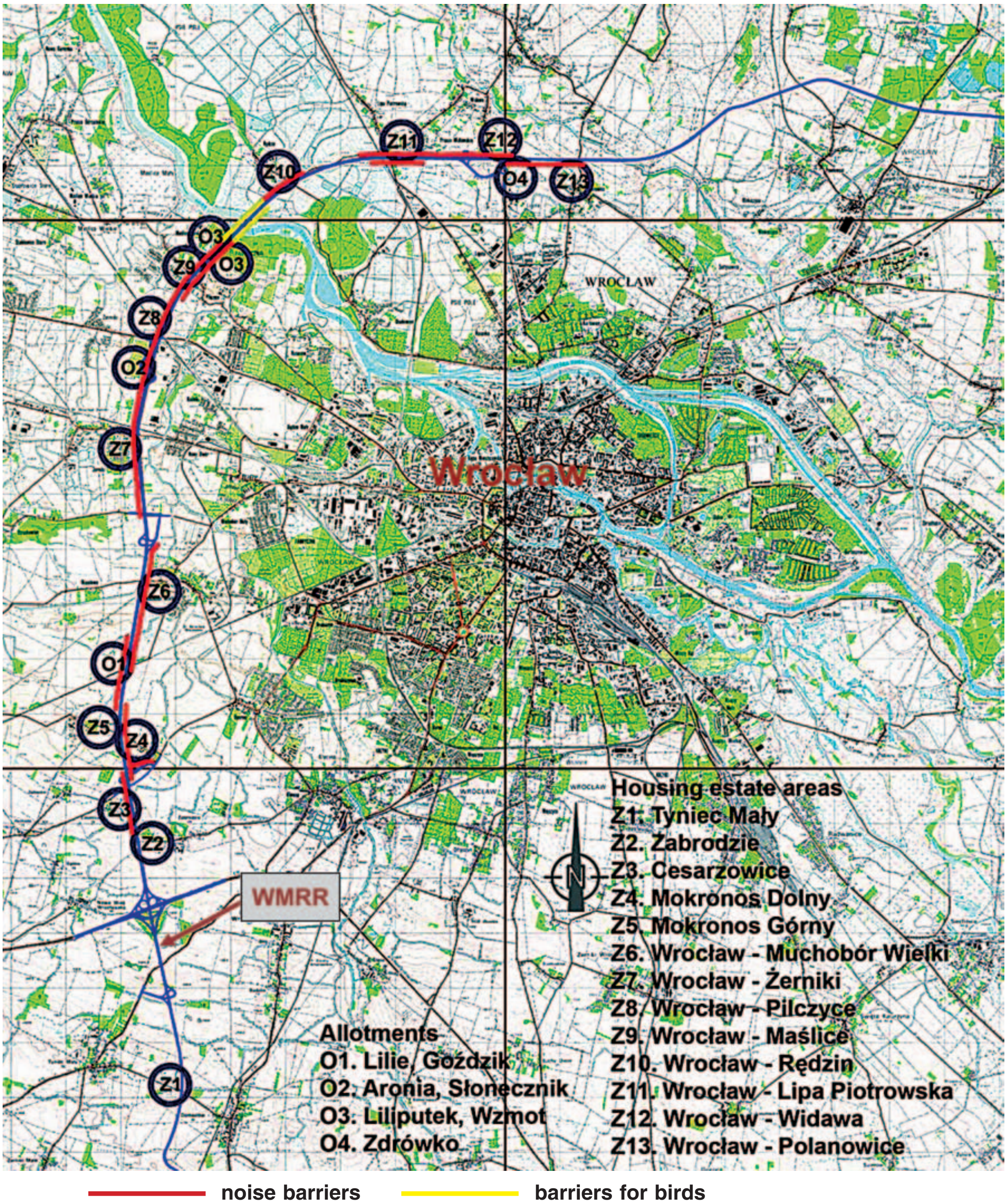

Figure 1. Location of Wrocław's motorway ring-road (WMRR). *Notes.* Z1–Z13—housing estates, O1–O4—allotments.

from the roadway. The existing built-up areas belonging to the neighbouring districts are located more than 150 m from the WMRR roadway, but the lands designated for housing developments in the local development plans come as close as 30–50 m to WMRR.

3. INVESTIGATION METHOD

DataKustic's professional software Cadna A version 3.5 was used for calculating road noise. A three-dimensional terrain model was developed on the basis of digital maps of the area and the designed alignment of WMRR (Figure 2). In order to evaluate the calculation error, a comparative analysis of measurements and calculation results was carried out for the existing motorway A4. For distance d = 20–200 m the differences between the measured and calculated values of L_{AeqT} did not exceed 1 dB. All noise calculations were performed using two methods: RLS90 (a German method of calculating road noise) and NMPB, the latter being recommended for road noise mapping by the European Noise Directive [5]. This procedure was adopted because of the uncertainty of determining values of noise level with calculation methods for complex terrain conditions.

Noise indicators were calculated for average-hour traffic in standard reference time intervals for daytime and night-time. The levels of noise emission for all specified variants of WMRR traffic conditions, i.e., traffic conditions forecasted for 2010–2030 for toll and free versions, and for minimum (MIN), intermediate (INT) and maximum (MAX) scenarios, were analyzed. The analysis showed that the differences between the predicted levels of noise emission amount to ±1 dB, but in 2010–2030 the level of noise emission may increase by 5 dB. Therefore for further calculations traffic conditions for the toll version of WMRR and the INT scenario were adopted and the differences between the INT variant and the MIN and MAX variants were assumed as a measure of the uncertainty of noise emission.

Daytime and night-time road noise maps were constructed for each section of WMRR with

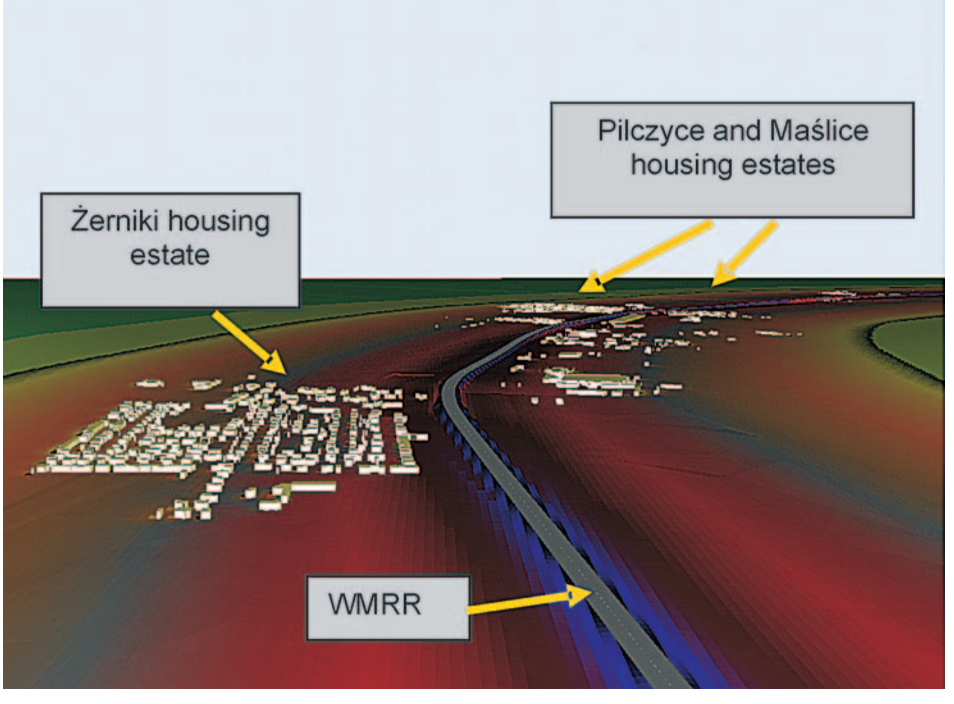

Figure 2. A sample three-dimensional terrain model; a road noise map—without barriers. *Notes.* WMRR—Wrocław's motorway ring-road.

different traffic conditions. The maps served as a basis for further analyses of (a) identification of areas legally protected against noise, which might be exposed to noise; (b) assessment of noise level on the boundary of housing estates; and (c) specification of requirements for environment protection against noise.

For identified areas exposed to noise, calculations were performed for the different variants of acoustic barriers in order to determine optimum solutions. Several alternative solutions (with different height h_{ei} and length l_{ei} of specific segments of noise barriers) were considered for each estate and village (Figure 3). Various designs of acoustic barriers were considered: straight, bent, and straight–bent barrier systems. When determining barrier specifications the following factors were taken into account: existing and planned land use, type of building development, alignment of WMRR, location of interchanges and approach roads, demanded limitations of barrier height on bridges and flyovers, the

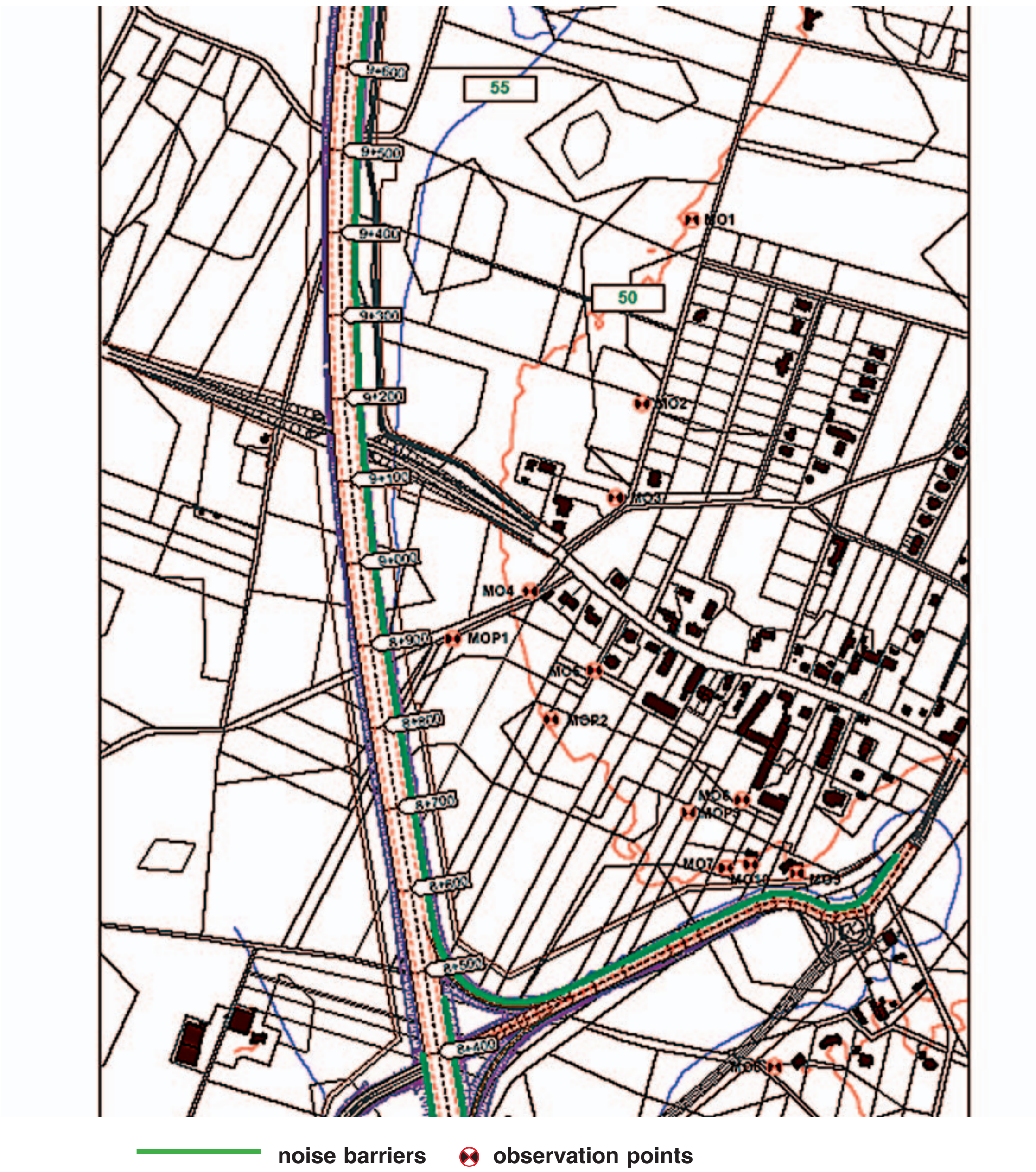

Figure 3. Sample noise calculations for Wrocław's motorway ring-road—with designed barriers.

necessity of ensuring proper visibility angles within interchanges, and so on. From 10 to over 20 different designs were considered for each identified area exposed to noise [6, 7]. The final version of the system of sound barriers was determined after taking into account existing technical limitations and urban development and economic factors. The specifications of the final version of acoustic screens were determined taking into account

1. estimated night-time noise levels (L_{AeqN}) on the border of the noise protected areas;
2. the effectiveness of the noise barrier design, taking into account the increase in noise reduction, in dB, per 1 m of increase in screen height; and
3. the uncertainty of L_{AeqT} calculation results in connection with point 2.

For design purposes it was assumed that at night-time the level of noise must not exceed L_{AeqN} = 50 dB for any housing development areas [8].

In the vicinity of noise protected areas WMRR will run for a considerable distance on an embankment and flyovers from a few to 20 m high. The calculations showed that for the designed alignment of WMRR an increase in barrier height of 1 m above height h_e = 6 m decreases noise by 1–1.2 dB. Very high acoustic screens (h_e > 6 m) on high viaducts and flyovers create urban obstruction; moreover, considering that the obtained increase in noise reduction is slight, they are not always economically justifiable.

4. UNCERTAINTY OF CALCULATION RESULTS

The uncertainty of the results of road noise calculation depends on the accuracy of the calculation method and on the errors arising from the uncertainty of the input data. Calculation method errors arise from the simplifications and limitations of a given calculation method and from calculation parameters, which have a significant influence on the calculation result [9, 10]. The uncertainty of calculation results increases for urbanized areas or varried terrain. It also increases with the distance from the road. According to Standard No. ISO 9613-2:1996 [11] the uncertainty of noise attenuation calculations amounts to ±1 dB for a distance up to 100 m and ±3 dB for a distance from 100 to 1 000 m.

In the case of WMRR, input data uncertainty applies to traffic conditions and the type of road surface. The uncertainty of calculation results, arising from the uncertainty as to traffic intensity, assumed on the basis of the difference between the calculation results for the MIN, INT and MAX scenarios on the average amounts to ±1 dB. Calculation result uncertainty may also be due to an assumption of the same percentage of heavy-class vehicles for daytime and night-time. According to statistics for existing motorways and national roads, the percentage of heavy-class vehicles at night-time is much higher. The estimation error may be 1–1.5 dB.

A comparison of the calculation results shows that the two methods yield similar results. But the determined road noise levels L_{AeqN} differ by ±(1–2) dB and at some observation points (for the road on an embankment) by as much as ±3 dB.

5. REQUIRED EFFECTIVENESS OF NOISE BARRIERS

The system of noise barriers for WMRR was adopted on the basis of the results of noise assessment carried out for forecasted traffic, taking into account the use of the land surrounding the ring-road and the local development plans.

The required minimum road noise reduction, in dB, is given by the relation:

$$\Delta L_{Aeq,\,min} = L_{AeqT} - L_{A,\,lim}, \tag{1}$$

where L_{AeqT}—noise indicator, $L_{A,\,lim}$—road noise limit.

L_{AeqT} and $L_{A,\,lim}$ determined for night-time are usually used in Equation 1 as critical in noise impact on national roads and motorways. For the areas surrounding WMRR the estimated

TABLE 1. Noise Barriers for Wrocław's Motorway Ring-Road—Housing Estates and Villages. Results According to Calculations Using the NMPB Method [5] and Cadna A version 3.5

Noise Protected Areas	Side	Symbol in Figure 1	Required Noise Reduction (dB)	Noise Barrier Length l_e (m)	Noise Barrier Height h_e (m)	Noise Barrier Noise Reduction $\Delta L_{A,e}$ (dB)
Cesarzowice	Left	Z3	5–11	1 190	4–7	8–12
Mokronos Dolny	Right	Z4	6–8	2 070	4–6	6–9
Muchobór Wielki	Right	Z6	5–8	2 380	4–6	6–10
Żerniki	Left	Z7	8–12	1 800	5–8	10–14
Pilczyce-Maślice	Left	Z8–Z9	9–10	2 090	5–7	11–13
Maślice	Right	Z9	10–11	1 290	5–7	10–13
Redzin	Left	Z10	6–11	930	4–6	8–11
Lipa Piotrowska	Left	Z11	10–15	1 890	4–8	10–15
Lipa Piotrowska	Right	Z11	11	1 100	4–6	10–12
Widawa	Left	Z12	5	1 100	4	7–8
Polanowice and Zdrówko allotment	Right	Z13 & O4	3–7	1 380	4–5	8–9

Notes. L_{AeqN} < 50 dB for observation points at h_o = 6 m for detached houses and h_o = 10–20 m for high-rise buildings.

required noise level reduction is 5–15 dB (Table 1). According to article 112 of the law on environmental protection [12], noise protection consists in ensuring the best possible acoustic condition of the environment by reducing the noise level at least to the limit value. Thus, the required effectiveness of the designed noise protection, in dB, should be

$$\Delta L_{Ae,\,p} = \Delta L_{Ae,\,min} + \delta L_{Ae}. \qquad (2)$$

There are no criteria for estimating the required or recommended value of δL_{Ae}. When determining the value of δL_{Ae} for design purposes one should take into account (a) a safety margin for the uncertainty of determining L_{AeqT} with the calculation method and (b) maximum possible noise reduction in order to ensure the best possible acoustic condition of the environment. It is always up to the designer to determine a sensible value of δL_{Ae} on the basis of an analysis of a given situation and the technical and economic feasibility of the designed noise protections. Noise barrier specifications, i.e., location, length and height of barriers, were selected according to the principle that the barriers should reduce the level of road noise below L_{AeqN} = 50 dB considering the traffic after the road is put into operation. However, for the areas located near WMRR, closer than 100 m from the roadway, it turned out to be technically and economically unfeasible to obtain a safety margin comparable with the uncertainty of the L_{AeqN} calculation results.

6. NOISE BARRIERS

Noise barriers with an overall length of about 22 000 m and a varying height of 4–8 m were designed for the housing estates (Table 1). They were designed by a team of acousticians, architects, and design engineers. In addition, 3–4 m high noise barriers were designed for the allotments located within the city boundary, on the basis of an agreement between the allotment holders and the developer (Table 2). For construction reasons, the height of the noise barriers on flyovers and bridges was limited to 6 m, and to 4 m on the bridge over the Oder river. The noise barriers were located on the road crown 2.25 m from the edge of the roadway and in the sections where the road runs in a cut, as close as possible to its edge. The distance between the noise barrier and the roadway is increased for technical reasons only, e.g., in parking bays. In order to increase noise reduction

TABLE 2. Noise Barriers for Wrocław's Motorway Ring-Road—Allotments. Results According to Calculations Using the NMPB Method [5] and Cadna A version 3.5

			Noise Barrier	
Noise Protected Areas (Allotments)	**Side**	**Symbol in Figure 1**	**Length l_e (m)**	**Height h_e (m)**
Lilie and Goździk	Left	O1	1 970	4
Aronia and Słonecznik	Left	O2	1 460	3–4
Wzmot	Left	O3	380	3
Wzmot, Relaksa and Liliputek	Right	O3	480	3

Notes. Observation points: h_o = 1.5 m.

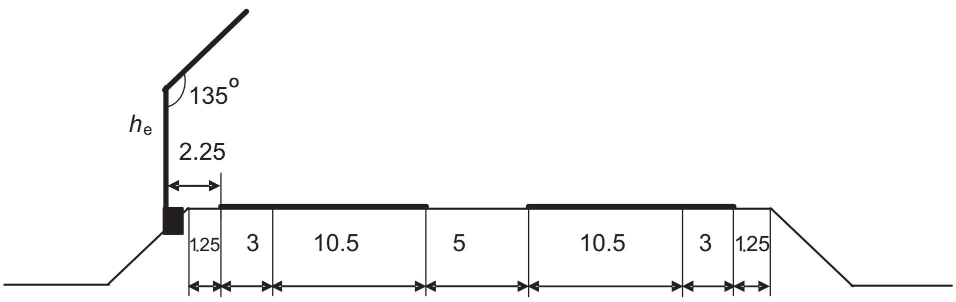

Figure 4. Location of noise barriers. *Notes.* h_e—height of accoustic screen.

for the same barrier height, barriers bent towards the roadway were adopted (Figure 4). For this purpose, individually shaped reproducible screen components based on a piece of a parabola were designed as part of the project. Straight noise barriers were designed for interchanges and approach roads only.

The noise barriers were designed mainly to be made of concrete with a ~5-cm thick sound absorbing layer on the side facing WMRR and finished with a texture suitable for climbing vegetation on the outer side. Transparent screens were designed for flyovers and bridges. They were introduced in longer concrete barrier sections in order to break the monotony of the latter. They will be made of 15–20-mm thick acrylic glass plates, covered with antigraffiti coating; bird scaring stickers will be stuck on the plates.

As part of the architectonic design, characteristic elements individualizing the interchanges within city boundaries, signalling emergency exits and marking the beginning and end of the bridge over the Oder river were proposed (Figure 5). The ends of screen lines were individualized, too. It was assumed that the characteristic architectonic elements of the interchanges were to be visible for both the drivers driving on WMRR and the drivers driving on the road crossing WMRR (Figure 6). One of the three colours of Wrocław's logo, i.e., yellow, red, or blue, dominates in each interchange within city limits. One of those colours dominates in the details attached to the acoustic screens, in road lamp fittings, in bridge components and also in the lighting of architectonic elements, suited to the colour scheme of a given interchange. Another element informing drivers about the approaching interchange is vegetation spread on a mesh on the concrete modules of the screens.

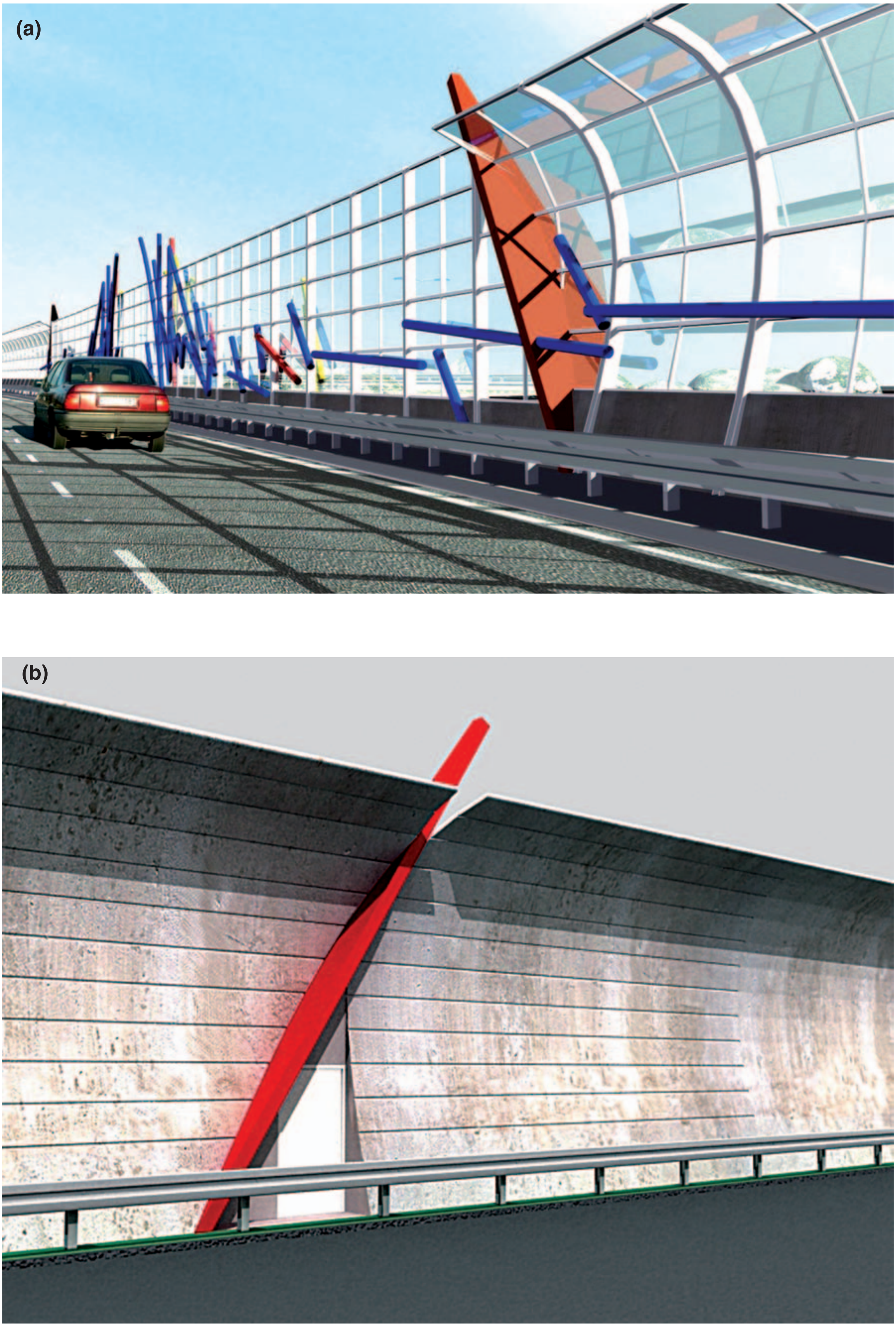

Figure 5. WMRR noise barriers—architectural elements: (a) a change in barrier type or height, (b) an emergency exit. *Notes*. WMRR—Wrocław's motorway ring-road. Design: Paweł Ogielski, visualisation: Jakub Chojnacki.

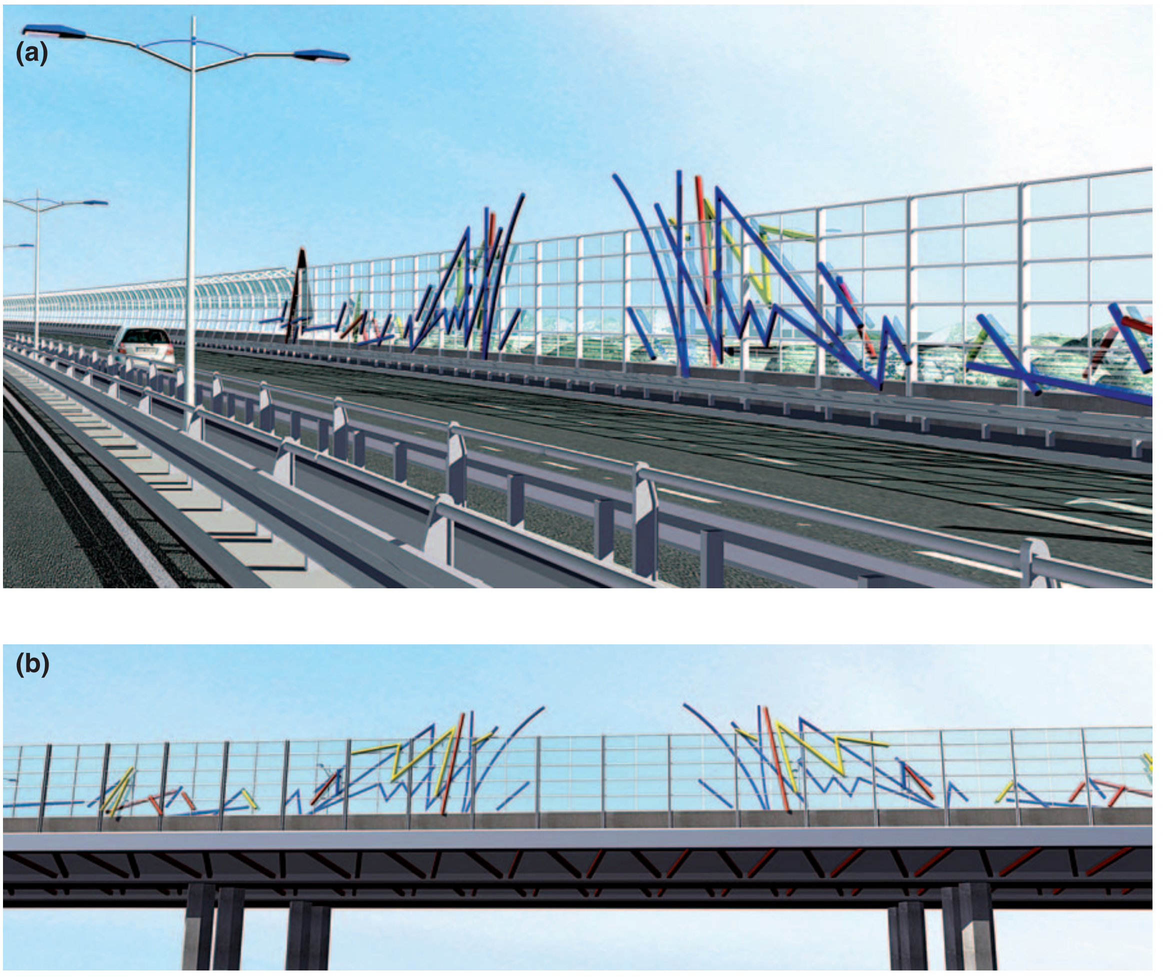

Figure 6. WMRR noise barriers—architectural elements of interchanges: (a) a view from WMRR, (b) a view from an approach road. *Notes*. WMRR—Wrocław's motorway ring-road. Design: Paweł Ogielski, visualisation: Jakub Chojnacki.

7. CONCLUSION

The acoustic screens ensure a reduction in road noise at night-time to a permissible level, i.e., L_{AeqN} = 50 dB, in most housing development areas for traffic forecasted after WMRR is put into operation. Only at individual points located most closely to WMRR may the noise limit be exceeded by 1–1.5 dB. For daytime the standards of the quality of acoustic environment will be met. The limitation, due to technical reasons, of barrier height to 6 m on viaducts and flyovers significantly curbs the possible noise level reduction in the housing estates located along stretches with the heaviest traffic, i.e., Żerniki, Pilczyce, and Maślice. The multi-family housing development in the Maślice estate on the right of WMRR is a problem area. Considering that high acoustic screens (h_e = 6–8 m) have been designed for the housing developments of Żerniki, Pilczyce, and Maślice, where the road runs on high flyovers and on an embankment, a further increase in barrier height would be unwarranted. If road noise exceeds the limit after project completion, it will be sensible to limit traffic speed at night-time. This measure is often used on ring-road sections of motorways passing through urbanized areas since it is hard to achieve screening effectiveness higher than 15 dB. Increasing screen height by 1 m results in an increase in screening effectiveness by 1–1.5 dB, which corresponds to limiting traffic speed by 10–20 km/hr.

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