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ARTICLE

New Concept of Animal Underpass - *Green Bridge*

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ABSTRACT

In Poland, the ecological corridor map overlaps with forests, as well as with the road network. The police have recorded near a 100% increase in animal mortality over the last decade. In most cases, bridges automatically serve as passages for animals, even if they have not been considered and designed for such a role. The following facts are importand: silence is positive for animals, natural guides are better then fences and walls, gentle lighting moderates car lights at night. Therefore, the semi-transparent canopy-type noise screens should be used, as well as olfactory tracks. The solution proposed here is beneficial for both the environment and road users. For the proper functioning of the bridge, it is crucial to take into consideration that animals are more efficiently guided by their smell than by channelling fences. However, the commonly used fences would also be provided. Olfactory traces can come in two kinds: animal faecal matter and mating scents. In a natural habitat, decreasing the immediate proximity between animals and humans should also be considered. A multi-criteria analysis was conducted to prove benefits both in terms of bridge maintenance effort and the impact on the environment. The criteria were selected on the basis of expert opinions.

1. Introduction

Protecting the environment poses a problem to different people, including road and bridge engineers. Even especially for them, perhaps. Motorways and highways are carefully fenced so as to isolate them from both people and animals contributing to eliminate mortality in the cases of animal intrusion on roads. Another open issue is the functioning of local roads, Fig. 1, which are not distinctly separated from their surroundings. Such roads witness fatal accidents i.e. running over medium-sized animals, as well as small wild and domestic animals.

(a)

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(b)

Figure 1. Insufficient distance between trees and the road edges
(a) national road S19 near Radzyn; (b) national road S63 near Ulan

The majority of Polish roads are not adjusted to safety transport which, in fact, is related to their geometry. Major, as well as well as secondary roads in wooded areas usually came in the shape shown in Figure. 1.

The two examples show the potential of a dramatic situation for the driver, as well as for the wild animal in the case of its intrusion on the road. Currently, the only environmentally positive solution is the speed limit of 30 km/h. However, the question arises whether it is feasible to drive at such a speed every day. It is also worth noticing that, in the Polish tradition, forests are open areas for walking, running, mushroom picking, etc.

In Figure. 2, two types of bridges are shown. In both cases the bridges automatically serve as bottom transitions for animals, even though they were neither considered nor designed for such a role, but simply due to their peripheral location.

(a)

(b)

Figure 2. Bridges in natural surroundings
(a) wooded area around a provincial road; (b) meadow crossed by a national road

These types of bridges are especially taken into consideration in the case of the *green bridge*. With regard to highway and expressway bridges, anti-glare barriers are commonly used, Figure. 3. An anti-glare barrier reduces the vehicle noise only partially.

(a)

(b)

Figure 3. Anti-glare screens on a bridge - transitions for animals located on national roads
(a) S19 near Kurow; (b) S17 near Lublin

The proposed *green bridge* type refers to covered/

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roofed wooden bridges, Figure. 4. In Europe, the most known bridge of this type is Kapellbrücke in Lucerne, Switzerland.

(a)

(b)

Figure 4. Examples of roofed bridges
(a) Crawfordsville Bridge, Oregon (1932); (b) Albania, near Skopje

2. Animal Underpass - *Green Bridge*

The ecological bridge presented here is a step towards the green bridge, albeit certainly not the last one. It is a result of various attempts including diagnostics and statistics of road traffic accidents involving animals, also taking into consideration the growing numbers of fatal accidents of game [1-2].

Upon the construction of the Lublin bypass (a city in Eastern Poland), the pro-environmental elements of bottom passages for animals located on the new road were critically analysed. An estimated increase in the costs of bridges/viaducts as compared to their total construction costs was caused by the addition of pro-environmental equipment and amounted to 15 – 25%, depending on the new road sector. Is it much? Only 10 years ago, constructed bridges were not equipped pro-environmentally, and from this point of view such an increase in costs may seem to be considerable, or even too high. Today, with the rising awareness of the importance of natural environment to people, above all, no voices of excessive costs can be heard. The common use of pro-environmental equipment in bridges may result in a decrease of costs due to market competition among the equipment producers.

This reflection accompanied the formulation of the technical solution in question, which can be modernised and adapted to developing ecological concepts and technology in general. The preliminary idea was formed seven years ago when photovoltaic panels and bridge health monitoring were novelties. Nowadays, the panels, next to wireless monitoring, are commonly used in bridge tests.

In consideration of the above, the Author finds that the proposed solution is an apt response to the needs of ecology with regard to transport, and completes a preparatory stage of conducted discussions, observations and analyses of the status quo, as well as meets the criteria of progress.

The *green bridge* proposal envisages supplementing an ordinary bridge with a canopy cover on the bridge and its approaches, as well as with additional equipment monitoring the migration of animals (cameras powered by solar panels).

As it seems, the most important element of the proposed solution is a monitoring of the migration of reptiles, as well as small, medium and big animals, including the option of identification of the number, sex, general physical condition or bottom passage behaviour of the migrants. Mounting continuous monitoring cameras boils down to equipping a bridge, while the question of storing and analysing the so-obtained database remains open. At present, there is no system of conducting such analyses, and sharing and applying their results in practice. Putting such a system, comprising numerous measurement points and bridges, into operation will result in a qualitative change in environmental knowledge, and, consequently, in a significant progress in the field of environmental protection. Such a short outline of the problem can only be justified by the fact that the Author specialises in bridges, with regard to which the bottom passage solution has been developed. In this sense, the proposition can inspire further interdisciplinary research.

Simultaneously, traffic monitoring and bridge condition monitoring is conducted in the same way, Figure 5.

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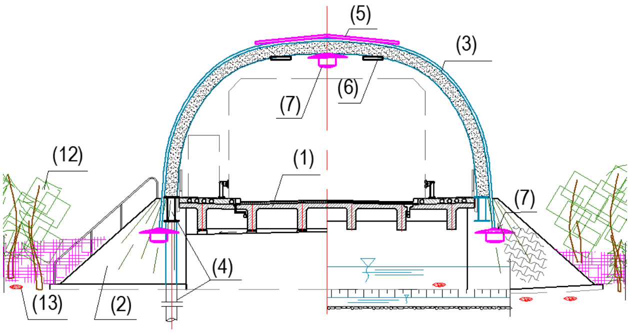
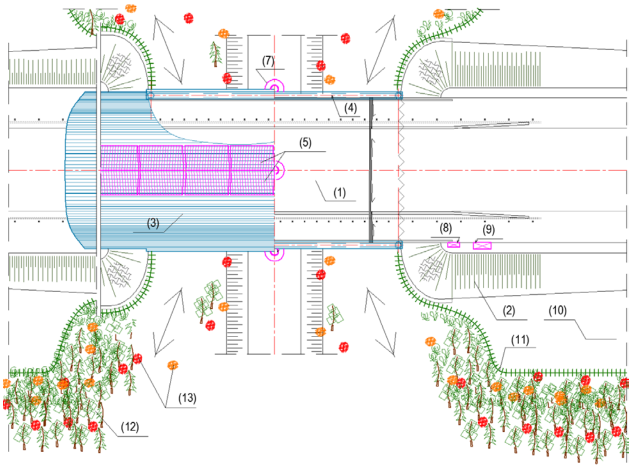


(a)



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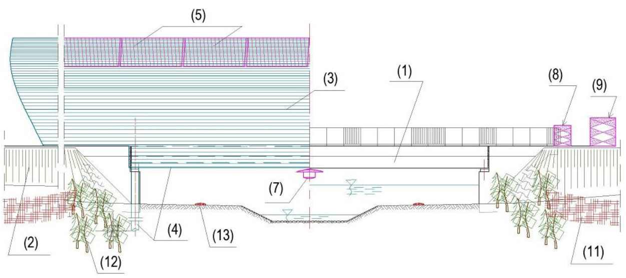

(c)

Figure 5. The *green bridge* technical proposal (a) plain and side views; (b-c) cross-section.

Components: 1- existing bridge, 2 - scarps of road embankments, 3 - canopy cover over the bridge and its approaches, 4 - in the case of an existing bridge, an additional carrying frame for the canopy, 5 - photovoltaic panels, 6 - LED lighting, 7 - environmental and road traffic monitoring cameras, 8-9 - boxes for accumulators and the wireless data transmitting apparatus, 10 – approx. 20 metres wide meadow strip separating the forest from the road, 11- guiding fences, 12 - forest approaching the bridge opening, 13 – olfactory tracks for animals.

The paper discusses two technical options, i.e. the case of a new bridge and the case of an existing bridge, which pose different technical problems and are related to different financial processes of construction and reconstruction, respectively. Paradoxically, the costs, which vary in terms of final amounts, are similar in respect of unit costs.

Assuming social acceptance of bearing additional costs with regard to pro-ecological equipment, the construction of a new bridge is simple. The structure can be designed according to the currently binding technical standards and ecological requirements straight away, as well as new solutions and concepts can be applied. The construction period is not significantly longer.

In the case of the adaptation of an existing bridge, it is necessary to reconstruct/expand it, as well as to strengthen its load bearing elements, more often than not. Renovation work may be more complex as compared to the construction of a new bridge.

The following assumptions were taken into consideration [3-4] :

(1) the proposal refers to existing bridges, nevertheless, a new bridge can also be designed in the proposed way,

(2) a bridge is over the water or is only a passage for animals, especially if it runs over a migration corridor for animals,

(3) is located in a non-urban area, especially a forest or a meadow,

(4) pedestrian traffic is minimal, however, a pavement of a single pedestrian clearance gauge, of the width of 0.75 + 0.5 = 1.25 m, and the other one for technical service and maintenance, of the width 0.75m, should be provided,

(5) in the case of intensive bicycle traffic, the sidewalks should be redesigned to fit a proper clearance gauge,

(6) typical environmental equipment/devices are installed, as well as apparatus for continuous environmental wireless monitoring,

(7) before the canopying, the bridge structure should be renovated and adjusted to current or future traffic needs.

In the case of existing bridges, the water clearance gauge was designed under the hydraulic and hydrologic conditions which constitute *necessary requirements*. Additional rules may be taken into consideration, too. These additional conditions are related to environmental needs e.g. the openness index or conditions resulting from geomorphology i.e. deep and narrow canyons, for instance. Nowadays, designed structures generally meet all of these conditions. In this sense, it is a situation corresponding to the notion of *sufficient conditions*.

3. Assessment Methodology

The technical proposal in question is new in the true sense of the term. It has never been known or discussed in the presented or similar form.

The aim of a multi-criteria analysis is to assess the probability of its acceptance or rejection by opinion-forming, environmental and road and bridges engineering

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milieus. The experts represent various professional disciplines. Their common denominator is their acceptance of the principles of sustainable development, especially pro-ecological processes.

The research consists of two stages. In the first stage a group of experts is familiarised / instructed / habituated with the technical proposal. At this stage, the experts discuss and evaluate the proposed sub-criteria. Slightly differently from the classical form of Delphi Method, one does not aim to moderate extreme positions here, but can deem some sub-criteria irrelevant, negligible instead. Individual experts can apply or change their evaluation of the sub-criteria in the first and second stages.

First of all, the experts establish the validity/elevance of the sub-criteria applying reference measures on the grading scale from 2 to 5.

It is simultaneously assumed that an in-depth discussion of the sub-criteria will result in the convergence of the second stage assessments. In the case of certain boundary divergences, i.e. the occurrence mainly of the boundary values 5 or 2, e.g. in the evaluations performed by two out of five experts, two options of a certain „dilution" of the extremes are allowed, as follows:

(1) Expanding the group of experts by two more specialists representative of the areas where the boundary evaluations occur,

(2) Applying the modified exceedance measure of 95%, e.g. [5], which will naturally favour conservative evaluations

$$f_{95\%} = \left\{ \begin{matrix} f_{m(n)} - 0.1\, k(n) \\ f_{lowest} + 0.4 \end{matrix} \right\} \quad (1)$$

Sub-criteria assessments are not directly applied in the second stage, but the experts are well familiarised with the meaning and sense of the basic criteria: ecological, technical and financial.

The second stage is concerned with three technical variants of the green bridge. The grading scale of 2 to 5 is again applied. The variants are graded on the scale from an ordinary bridge, i.e. an unarranged bottom passage, to the variant corresponding with the technical proposal in question. In the case of the remaining variants, the simplest criteria assessment standards were applied

$$\forall_{k=I,II,III.}\ \forall_{i=1,2,3,.}\quad m_{ki} = \frac{1}{25(or\,30)} \sum_{j=1,2,\dots,5,(or\,6).} C_{ijk} \quad (2.1)$$

$$\forall_{k=I,II,III.}\quad m_k = \bar{m}_k = \frac{1}{3} \sum_{i=1,2,3.} m_{ki} \quad (2.2)$$

where m_j - k-variant assessment, m_{kj} - detailed assessment

C_i- ecological, technical and financial criteria successively,

C_{ij}- five experts' assessments of the three criteria,

C_{ijk}- assessment value in k-variant,

25 – reference value for an assessment of the criteria in tables 1, 3.2, 3.3 and 4; 30 - reference value in tables 2.1, 2.2; 3- number of the assessed criteria in k-variant.

4. Expert Assessment

The analysed technical solution is something new and, as such, requires an assessment based not only on specific knowledge and experts' experience to date, but on extrapolation and anticipation of its accuracy and potential defects, the same applying to its monitoring equipment [6-7].

Three variants of a lower animal passage were considered, based on a bridge of the width equalling the average width of a Polish bridge, i.e. L≈20 m.

Experts in question represented various disciplines: ecology, civil engineering, computer science, road and bridge administration.

It was assumed that experts' specialisations, experience and professional practice generate subjective assessments with internal weighting assigned to their particular disciplines, [8].

The costs of construction work and monitoring equipment installation were assessed according to relevant prices in Poland in the period of the last three years. The reference unit for the costs in question are the average costs of the construction of a 20-metre long bridge with an 8-metre wide road and two pedestrian pavements of a useable width of 1.5 m. The total bridge width B = 12 m was assumed.

The second stage concentrated on a multi-criteria assessment of the three variants of a lower animal passage. The aim of the analysis was a relative assessment of the proposed technical solution, i.e. the *green bridge*.

5. First Stage – Description of the Criteria and Sub-criteria

$C1$ – ecological criterion and sub-criteria

(1) c11- continuous monitoring of the lower passage for small, medium-sized and large animals,

(2) c12 – adjustment of the lower animal passage (narrowing),

(3) c13 –sensitive place for animals – predators and their victims,

(4) c14 – decreasing (eliminating) animal mortality on roads,

(5) c15 – significant reduction (elimination) of vehicle generated noise on roads – a muffling zone,

(6) optical reduction of the impact of vehicle lights.

Nowadays, when constructing or reconstructing a bridge, solutions regarded as pro-ecological are commonly used. Despite a systematic or periodic study of wild animals' migration routes, their location is not 100% sure, especially at points where they cross with existing roads. Continuous monitoring of animal migration near bridges is cognitively justified. Cases have been reported where an animal passage became the feeding ground of predators; hence, an assessment of the occurrence and range of this phenomenon is required. Teaching animals to use a passage, apart from guiding fences, may be supported with organoleptic baits. It has been assumed that animals are encouraged to use a passage in a silent area, where the vehicle noise has been muffled, as well as with weak lighting reducing an optical shock caused by vehicle lights. The purpose of such passages is reduction or local elimination of animal mortality on roads.

Table 1. Assessment of ecological sub-criteria relevance

	c11	c12	c13	c14	c15
Ecologist	5	4	3	5	5
Greenpeace.pl	5	5	2	5	5
Local politician	4	3	2	5	5
Road administrator	2	2	2	5	5
Road journalist	4	4	2	5	5
$\left(\sum_j C_{1j}\right)/25$	0.8	0.72	0.44	1	1

The highest relevance was found in sub-criteria c14 and c15 with the experts' assessments being homogenous. Sub-criteria c11 and c12 were deemed auxiliary, while sub-criterion c13 – marginal, as too specific.

*C*2 – technical road and bridge criterion – sub-criteria:

(1) c21- construction of a new structure – increased costs,

(2) c22 – preparation of an existing structure – additional costs,

(3) c23 – protection of a bridge against environmental impacts (rain, snow),

(4) c24 - monitoring the technical condition of a structure as well as road traffic,

(5) c25 – repairs and maintenance of monitoring and power supply equipment,

(6) c26 – reduction of maintenance work – improving the durability and longevity of a bridge,

(7) c27 – traffic organisation, collisions, accidents including fire, surface renovation.

In the case of a decision to renovate an existing bridge, additional costs include re-profiling of the riverbed under the bridge and in the vicinity, reconstruction of pavement supports to install noise barriers, Fig. 5 d – f. Modernisation of the road surface and pavements is also required, as well as installation of traffic safety systems. Optionally, independent supporting elements for noise barriers located on the sides of a bridge can be considered.

Bridges constructed currently to ecological standards are not equipped with monitoring devices registering animal migration and road traffic. Consequently, additional costs of the installation of a photovoltaic power supply, batteries, cameras and wireless devices for the obtained data transmission should be taken into account.

A canopy / roofing noise barrier on a bridge and its approaches creates an almost silent zone which encourages wild animals to use its lower passage, while weak internal lighting decreases the contrast caused by vehicle lights.

Putting a roof over a bridge significantly reduces environmental impacts. It regards snowfall especially, as it also means that de-icing of the road surface and pavements by means of salt, aggressive to the structure and causing cryohydrates, can be eliminated. It improves the longevity of the structure as well as road safety.

There are, however, negative effects of bridge roofing, which are generally characteristic of tunnels. These are: fire resulting from e.g. a collision, aerodynamic overpressure and underpressure, and the necessity of extra ventilation when laying new asphalt surfaces for instance.

Due to criteria c11 and c12 being mutually exclusive, the relevance assessment was carried out in two independent variants.

Table 2.1. Assessment of technical sub-criteria relevance – new bridge construction variant

	c21	c23	c24	c25	c26	c27
Road-bridge designer	4	5	5	2	5	4
Contractor	5	3	3	2	4	3
Local politician	5	5	3	2	5	4
Road administrator	2	2	5	5	5	5
Road journalist	3	2	2	2	4	3
$\left(\sum_j C_{2j}\right)/30$	0.63	0.70	0.60	0.43	0.77	0.63

Criterion c25 was deemed marginal. The relevance of the remaining sub-criteria varies, but their assessment span is characterised by an approx. 10% variation coefficient, which, from the technical point of view, can be regarded as a convergence. In terms of detail, sub-criterion c26 is the most relevant, while c21, c23, c24, c27 are auxiliary.

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Table 2.2. Assessment of technical sub-criteria relevance – existing bridge variant

	c22	c23	c24	c25	c26	c27
Road-bridge designer	5	5	5	2	4	3
Contractor	4	5	2	3	2	3
Local politician	3	5	4	3	3	4
Road administrator	5	5	5	5	5	5
Road journalist	4	2	2	2	5	4
$\left(\sum_j C_{2j}\right)/30$	0.70	0.73	0.60	0.50	0.63	0.63

In the case in question, the assessment of the sub-criteria relevance amounted to approx. 13%. C25 was deemed the least relevant. Disregarding c25, the variation coefficient equalled 8.3 %. Therefore, the relevance of the remaining sub-criteria wa similar. The most relevant among them was sub-criterion c23.

*C*3 – costs, cost components.

Estimation of costs was performed by means of assuming the price of a new bridge without ecological equipment in euro as the reference value.

Provided that the cost of 11 (sm) m^2 superstructure equals 977≈1000 euros (PLN 4,200.00), the final price of the bridge construction is 20*12*1,000=240,000.00 euros (PLN 1,000,000.00).

For the purposes of the analysis it was assumed that the price of a new bridge is

250,000.00 euros ↔ 100%

A relative measure expressed as a percentage was applied, where the point of reference for costs was the price of a new bridge. Renovation of an existing bridge with improvement of the load-bearing capacity of its superstructure to the standards of new bridges amounts to approx. EUR 70,000.00, i.e. 30% of the costs of a new bridge.

The costs of design documentation were estimated at 3-5%. For the sake of simplification, they were not considered.

1 sm of a typical noise barrier of the height of 3 m costs approx. EUR 470. Assuming the barrier length of 2*(3*20 m) = 120 m, i.e. 360 sm. The price of a noise barrier is EUR 170,00.0 which constitutes approx. 70% of the price of a new bridge.

Optionally, on bridges and simultaneously, on their lower passages for animals, anti-glare barriers can be installed, reducing noise only to a certain extent. The price of 1 sm of such a barrier amounts to EUR 165.00; therefore, in the case of a 360 sm barrier it is EUR 60,000.0, i.e. 25% of the price of a new bridge.

In Poland, there are only a few transparent canopy/tunnel barriers, hence their prices are high, as it is a new product on the market. It is assumed that the price of a canopy barrier is approx. 2.5 times higher than the price of ordinary noise barriers and amounts to EUR 510,000.0, i.e. 170% of the price of a new bridge, in the case under consideration.

The price of monitoring equipment (photovoltaic panels, batteries, data transmission wireless devices, cameras and sensors) was estimated at EUR 50,000.0, i.e. 20% of the price of a new bridge.

A canopy-type barrier protects a bridge against atmospheric impacts, reducing steel and concrete corrosion. It is assumed that the longevity of a bridge structure is improved as a result, and, consequently, structure renovation is required once in 50 years. Nowadays, it is approx. once in 30 years. Furthermore, it reduces the maintenance costs to one-off renovation within the period of 100 years. In terms of percentage, it amounts to 30% of the price of a bridge.

The assessment did not take into consideration the costs of asphalt surface replacement as it falls into the scope of the standard road surface maintenance.

Furthermore, the price of the purchase and installation of guiding fences was also not included due to the fact that it does not exceed EUR 5,000.0, i.e. 3% of the price of a bridge.

To sum up:

- c31 – the cost of a new bridge - 100%,
- c32 – the cost of existing bridge renovation - 30%,
- c33 – the cost of a noise barrier - 70%,
- c34 – the cost of an anti-glare screen - 25%,
- c35 – the cost of a canopy-type barrier - 170%,
- c36 – the profit from longevity improvement - 30%.

It is assumed that sub-criteria c31 and c32 are mutually exclusive, therefore, two separate cases are considered.

Table 3.1 shows relative prices of ecological equipment in various configurations, taking into consideration the costs of a one-off structure renovation.

Bearing in mind the relative costs, the relevance assessment of the ecological equipment configuration variants was conducted.

Table 3.1. Relative prices of a green bridge in two separate cases [%]

	c31	c32	c33	c34	c35	c36	∑
	100		70				170
New bridge	100			25			125
	100				170	30	240
		30	70				100
Existing bridge		30	25				55
		30	170				200

Once again, the ordering grades from 2 to 5 were applied. The experts were informed that the price criterion could not be considered in terms of contractor vs. investor. In other words, the lowest cost – the highest profit preference in not applicable. That which was important was relevance which could be interpreted as acceptability.

Table 3.2. The case of a new bridge

	c31	c33	c34	c35	c36
Investor	4	3	5	2	2
Contractor	5	4	3	5	2
Local politician	4	2	5	2	5
Road administrator	5	2	4	5	5
Road journalist	5	2	3	5	5
$\left(\sum_j C_{3j}\right)/25$	0.92	0.52	0.8	0.76	0.76

Table 3.3. The case of an existing bridge

	c32	c33	c34	c35	c36
Investor	4	3	5	2	2
Contractor	5	2	5	5	2
Local politician	3	2	5	2	5
Road administrator	2	2	4	5	5
Road journalist	5	2	4	5	5
$\left(\sum_j C_{3j}\right)/25$	0.76	0.44	0.92	0.76	0.76

The obtained results presented in the tables were convergent. Criterion c33 could be deemed negligible. The use of an anti-glare barrier was confirmed as appropriate, c34. Simultaneously, the most expensive solution, i.e. a canopy-type barrier, c34, was found acceptable.

6. Stage II – multi-criteria analysis

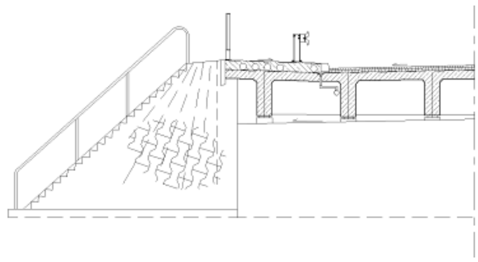
The applied method of the proposed structure assessment is a modification of *Delphi method* [9]. Online communication replaced a face-to-face contact.

Three variants of a lower passage for animals were considered. It was provisionally assumed that the bridge in question was new or an existing one equipped ecologically in different ways.

Variant I – the bridge water clearance gauge (bridge light) is used as a passage for animals without any pro-ecological equipment. There only are road signs warning about the possible appearance of animals and limiting vehicle speed, Figure 5.a.

Variant II – applied in currently constructed bridges with guiding fences and ordinary noise or anti-glare barriers, Figure 5.b.

Variant III – the new proposal discussed in the paper. Continuous monitoring of animal migration and the traffic on the bridge, Figure 5.c., as well as the possibility of monitoring of the work of the bridge. Monitoring, lighting and data transmission devices are powered by photovoltaic panels. The bridge and its approaches are covered with a closed noise barrier. A traditional way of guiding animals to the bridge by means of fences is complemented by the afforestation of the vicinity of the bridge, as well as by olfactory tracks, Figure 1. a-c.



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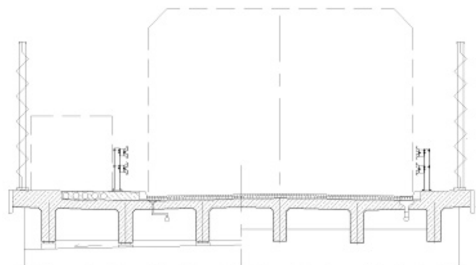

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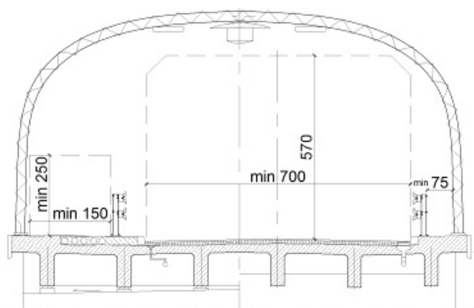

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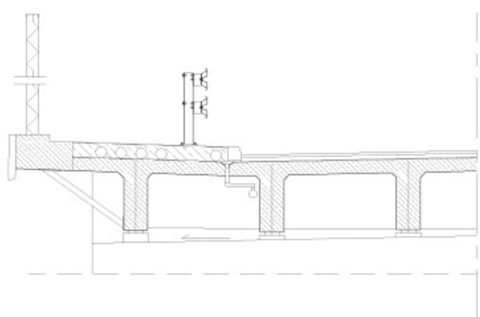

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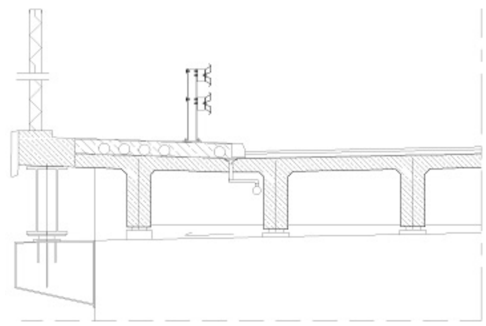

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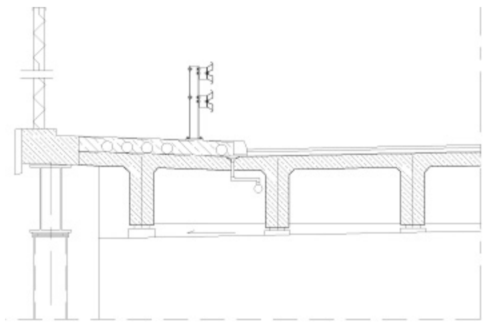

f)

Figure 5. Noise barrier location, as well as a different arrangement of the bridge side and cantilever strengthening a) cross-section of a typical RC bridge of the length of approx. 20 m b) vertical noise barriers c) canopy-type noise barrier d) strengthening struts e) by adding a simple beam on short steel cantilevers f) steel beam frame attached to a pile head.

Table 4. Comparison of the ecological variants equipment on a bridge used as a lower passage

	I			II			III		
	C1	C2	C3	C1	C2	C3	C1	C2	C3
Ecologist	2	2	2	3	3	2	5	4	3
Designer	3	4	5	5	4	3	5	4	3
Local politician	2	2	4	4	4	4	5	5	3
Road administrator	3	2	3	4	4	3	4	5	4
Road journalist	2	3	3	3	3	3	5	4	4
$m_{ki} = \left(\sum_j C_{ijk}\right)/25$	0.48	0.52	0.68	0.76	0.72	0.6	0.96	0.88	0.68
$m_k = \left(\sum_i \sum_j C_{ijk}\right)/75$		0.56			0.69			0.84	

7. Conclusions

(1) When discussing the result of the variant relevance assessment, it should be highlighted that the experts took into consideration the notes regarding the price as a decisive criterion, and accepted it to be as important as the other criteria. The fact that the quality of a pro-ecological solution was taken into account was expressed by assigning the highest relevance to the new variant III. Accordingly, the lowest relevance / acceptability regarded variant I - without ecological equipment.

(2) The obtained results can be interpreted as an expression of the understanding that it is necessary to bear additional costs of environmental protection. It can also mean that the increased costs have been satisfactorily justified.

(3) It is a technical proposal which can be immediately implemented.

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