Fifth International Conference on Construction in the 21st Century (CITC-V)
"Collaboration and Integration in Engineering, Management and Technology"
May 20-22, 2009, Istanbul, Turkey

Green Bridges for Minimizing Fragmentation of Landscape

Jan Pencik
Profession Society for Science, Research and Consultancy of Czech Institution of Civil Engineers
Prague, Czech Republic
pencik.j@centrum.cz

Abstract

Sustainability can also be understood as long-term compatibility. Its basic pillars are ecological, economical and social-cultural. From the ecological point of view there are three basic protection elements: protection of sources, ecosystems and human health. The use of natural sources must be evaluated not only from the point of view of price and quality but also it´s necessary to consider all impacts on surrounding environment. In case of road structures, among which belong motorways and highways, it is necessary to deal with problems of possible defragmentation of biotopes leading to isolation of partial populations. Special corridor structures – so called *ecoducts*, which serve towards minimization of population fragmentation, are suggested in order to preserve current possibilities of animal migration. In the process of design of ecoducts there is a great necessity of careful evaluation of what kind of animals they are intended for, further their ground location, facture, adjustment of surrounding and access areas.

Keywords

Sustainable structures, Fragmentation, Ecoducts

1. Introduction

Building structure undergo several basic cycles from planning and designing over construction, operation and servicing to eventual demolition. Complex approach to all construction cycles that make provision for ecological, economical and social-cultural aspects as safety and reliability, esthetical criteria, functionality for whole projected lifetime, natural impact, construction costs, transportation costs but also demolition and recultivation is called sustainable construction.

Sustainability can be understood also as long-term compatibility. Its basic pillars are ecological (see chapter 2), economical and social-cultural. From ecological point of view there are three basic protective elements: protection of sources, ecosystems and of the human health. Solutions that respect only some elements may act negatively on other. From here is necessity for wide complex approach with respect to all known impacts. This approach should lead to balanced compromise solution.

2. Ecological Pillar for Longterm Compatibility

Laws of respective countries clearly establish which structures are necessary to subject process of assessment structure impact on nature (EIA) (Mayer and Foral, 2008), (Šikula, 2008). The use of natural materials must be evaluated not only from quality and price point but also it´s necessary to consider all impacts on surrounding environment adjust of land appropriation and forest and adjust level of noise emissions, harmful pollution and waste. It is necessary to evaluate current natural relationship on given area with sufficient lead based on raw biological exploration. If there are special protected animals or vegetation connected on original ones that permanently of temporarily extinguish because of construction and can be relocated to new locality it is necessary to realize this preservation transfers.

Based on evaluation of current state of impacted areas must be construction processes optimalised so there is minimal harm to environment and we must also design steps that brings obtainable harmony of structure with environment also after finalization of structure including recultivation of surroundings, respectively it´s putting into original state.

2.1 Impact of Road Structures

Construction of huge road structures such as expressway and motorway roads cannot bring irreversible effects or damages of biological relations which in case of road structures can affect large areas or can bring isolation of populations.

For many animal types are roads and highways or more precisely traffic hardly surpassing barriers with consequence in smaller or bigger isolation of local populations (Adamec *et al.*, 2005). Practical consequence can be briefly characterized as restriction of common movement of animals in landscape, fragmentation of biotopes leading to isolation of partial populations with negative impact on their genetical diversity and collisions of vehicles with animals that faces to killing many specimens on roads, serious traffic accidents in case of collision with bigger animals with serious effects on health and even life of people and material damages.

High capacity and intensively used roads makes mainly for bigger mammals with difficulty overcome barriers that cause fragmentation of landscape and populations (Žák, 2008). This forms so called "island" populations that are very vulnerable. Population fragmentation is becoming one of most threatening factors in Europe for many animal species mainly for populations of bigger mammals. Arising possibility of population fragmentation can be derived from density of highway network (Table 1).

Table 1: Highway Network Density (km/1000 km^2) in Selected Countries - Year 2004 (Eurostat, 2008)

	Belgium	Czech Republic	Denmark	Germany	France	Netherlands	Austria	Slovakia	United Kingdom
Highway (km)	1747	518	1010	12037	10379	2342	1677	316.2	3657
Area (1000 km^2)	30.511	78.866	43.094	357.021	547.030	41.576	83.853	49.034	244.870
Network density	57.3	6.6	23.4	33.7	19.0	56.3	20.0	6.4	14.9

Fragmentation of environment made by road structure is with human acting further increasing. To prevent direct collision of animals with traffic are along most of the roads mainly highways made fences that hamper entering of bigger animals on roads. It is precaution that in case of proper realization and servicing fulfills its function; however at the expense of maximum of barrier effect restraining overcome of the road.

For maintaining possibility of animal migration even over mentioned restrictions are in present for newly constructed highways and motorways in place of biocorridors designed special structures – *ecoducts*. These structures serve for minimization of animal population fragmentation. During their designing it is necessary to take into account for what animals are determined, their location in terrain preferably in place of their current natural migration traces. The way of designing and implementation must enable their further functional use. Therefore is necessary to chose proper shape and used materials and also modification of their surroundings and access places.

3. Special Ecological Structures - Ecoducts

Ecoducts (Table 2) that serve primarily for animal migration or primarily for transfer of road over natural obstacle with secondary function of animal migration can be divided according to several criteria's. For example dependency of location of ecoduct with regard to surrounding terrain and road or according to animal category for which is ecoduct made.

Table 2: Division of Ecoducts with Dependency on Location of Ecoduct with Respect to Surrounding Terrain and Road (Hlaváč and Anděl, 2008)

Ecoduct	Subways	Culverts	Pipe culverts
			Frame culverts (Figure 1a)
		Bridges over road	Multipurpose bridges
			Particular bridges (Figure 1b)
			Large nature bridges - total span over 100 m (Figure 1c)
	Overpasses (green bridges)	Bridges across road	Multipurpose bridges
			Particular bridges - ecological footbridge (Figure 1d), bridge (Figure 1e)
		Tunnels	Tunnel - ecological tunnel (Figure 1f)

Selecting of suitable type of ecoduct and its load bearing structure is influenced by position of vertical alignment of road in place of original animal migration corridor. With respect to vertical alignment of road is possible to divide ecoducts into two basic types – subways and overpasses so called *green bridges*. Subways have vertical alignment of road above terrain and overpasses under terrain. For both types of ecoducts is valid that surrounding landscape must be adjustment so that animals have no chance how to get on road and instead are navigated to ecoducts (Brnušák *et al.*, 2003).

Subways are possible to divide into culverts and bridges over roads. Pipe and frame culverts (Figure 1a) situated in pads of embankment of road soil body serves mostly for migration of small animals, amphibians and reptiles. Bridges over roads of different types transfer road over natural or artificial obstacles. Simultaneously is necessary to design them so they can serve as migration paths for middle and big animals. Large natural bridges fulfill criteria for migration of all animal categories (Figure 1c).

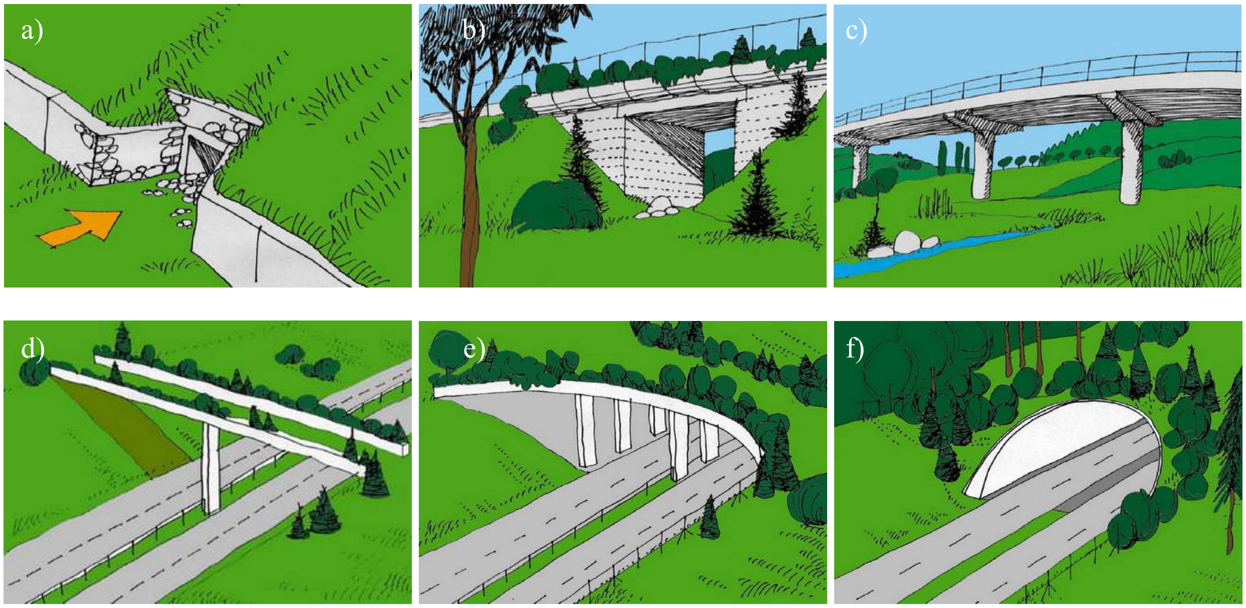

Figure 1: Ecoducts (Brnušák *et al.*, 2003)

Overpasses (green bridges) are possible to divide on ecological bridges (Figure 1e) eventually foot bridges (Figure 1d) over roads and tunnels (Figure 1f). Ecological bridges over roads are in most cases build in place of crossing of constructed road with forest or field roads. They are in most cases suited for transfer of roads over constructed highways with supplementary function of use for transfer for small and middle-big animals or for all animal categories. Last type of green bridges is ecological tunnel it means structures longer than 50 m. Ecological tunnels are most ideal from all types of ecoducts transferring highway under level of biocorridor.

3.1 Green Bridges

Green bridges are most often designed as ecological bridges over roads and their part are forest or field roads. In sporadic situations are only determined for animal migration. In most cases are load-bearing structures of green bridges designed as reinforced cast in place or prefabricated spilled frame structures with constant or variable thickness. Central line has shape of arch or dome because frame structure with broken axis does not fit naturally into the landscape. Ground plan is mostly straight since this shape fulfills esthetical aspects and naturally fits into landscape that is artificially split by highway or motorway and creates migration paths for all animal categories. Besides straight ground plan is for economical reason also used hyperbolic one. Disadvantage of this shape is reducing of width of ecoduct that is one of the important factors influencing function of ecological bridge. Where is possible are build ecological tunnels serving only for animal migration. Again are discussed spilled frame cast in place or prefabricated reinforced concrete structures with constant or variable thickness with center line in shape of arch or dome.

3.2 Factors Influencing Design of Green Bridges

Among factors influencing design, location and function of green bridges are width, surface treatment, surface ordering, location, technical equipment supplementary steps and loads.

From functional point of view is for green bridges one of main factor its width i.e. size of green bridges in axis of road. It is not possible to uniquely determine optimal width of green bridges for animal migration because width is directly related with animal size. So the width must be set so that green bridges reflect demands of migrating animals. In case of big animals is recommended standard width 45 ± 5 m. These parameters are usable only where other factors influencing function of ecoduct has optimal value such as location with minimal nuisance, perfect vegetation adjustment of ecoduct and natural connection of ecoduct on surrounding landscape. In case where parameters of location of ecoduct are not optimal is necessary to adequately adjust with of green bridges. For green bridges connecting several biotopes and that will be used except by big animals also by small one is recommended minimal width more than 50 m (Bank *et al.*, 2002). In case of small animals is recommended minimal size 20 m.

Ordering of surface is based on way of use of green bridges. Even minimal presence of human may discourage animal from using of green bridges. That is why is necessary to prevent human in using green bridges for example by dense vegetation or elevated banks (Adamec *et al.*, 2005). In cases where is necessary to use green bridges besides for animal migration also for transfer of forest or field roads is urgent to separate them. Roads should be designed on sides followed by continuous stripe of green vegetation.

Next factor influencing functionality of green bridges is surface treatment. Green bridges surface treatment must be done so it does not segregate green bridges from surrounding environment. At the same time is necessary to make visual separation of this structure from highways or motorways. Surface treatment should be designed in way it will imitate character of surrounding biotope and habitat.

Planting should conform to ecological aspects and should be done with timber species growing in proximity of green bridges. If there is forest or field road as part of green bridges its surface should have similar properties as hardness as surface or surrounding terrain. For example gravel, compacted mold or asphalt.

Technical equipment of green bridges should be as minimal as possible. There should be no unnatural barriers as concrete fencing or concrete water canals on or near to green bridges. Also lights of highway or motorways structures under ecoduct should be designed such it will not interfere and affect light conditions on green bridges and so it does not harm natural animal migration (Bank *et al.*, 2002).

Proper implementation of supplement steps including fencing of highways also impact resulting function of green bridges. Highway fencing near green bridges must be done so it will navigate animals on green bridges and will prevent them from entering highways. During implementation is necessary mind proper ending of highway fencing and its connection on green bridges fencing that will prevent possible animal fall on the highway. With protective function is connected height of fencing that should proceed between 1,6 m and 1,8 m including snow cover. In most cases is green bridges fencing done in same way as highway fencing i.e. wire netting. For separation of green bridges surface (field road and migration) is also possible to use fencing that must be unobtrusive and should not disturb or threaten animals. Suitable material for this type of fencing is wood or combination of wood and steel profiles.

4. Examples of Realisation of Green Bridges

Way of design and realization of green bridges is in EU countries very similar. For mutual comparisons are presented three chosen green bridges – ecological bridges build on motorways and highways in Czech Republic (motorway R35), Austria (highway A4 and 16) and Slovakia (highway D1). Besides ecological bridges there is presented also one ecological tunnel. Examples of ecological bridges in Germany are mentioned in (Foglar, 2008).

4.1 Czech Republic

In Czech Republic ecological bridges are mostly designed as reinforced one or multi chamber arch structures. Frame structures with broken axis are not used, as their shape does not naturally fit into landscape.

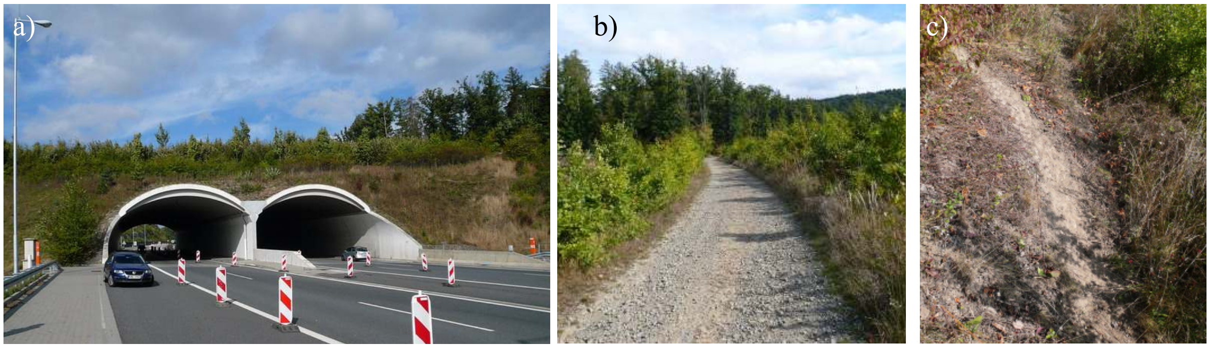

Figure 2: Ecoduct Velký Újezd

First ecological structure in Czech Republic is ecological bridge Velký Újezd (Figure 2a) with length 93 m build and opened in year 1999 in motorway R35 between Olomouc and Lipník nad Bečvou. It is reinforced concrete prefabricated cylindrical dome double chamber structure with middle wall in axis of motorway. Height of embankment is based on terrain relief from 5,50 m to 4,85 m. On surface with planted grass and bushes is located forest road (Figure 2b). Primary purpose was maintaining of biocorridor between both sides of deep cutting. According to some studies (Adamec *et al.*, 2005) is ecoduct not well located. There is only small forest connecting to ecoduct and at the same time is ecoduct too close to village. But in spite of studies there are alleys and footprints from animals that witness fulfilling its function (Figure 2c). The most important function is bridging of underwater stream.

In present, on Czech motorways and highways seven ecological bridges exist and three others are currently under construction.

4.2 Austria

On Austria highway A4 (Ost-Autobahn) in direction Wien –Budapest is in segment with length of 9 km made six ecoducts (green tunnels). They are designed as two-span reinforced concrete frames of length 60 m with middle wall located in axis of highway (Figure 3a) and facing with arch shape.

Figure 3: Ecoduct on Highway A4

All ecological bridges convey over highway A4 field roads or local roads. The surface of ecological bridges is fully adapted to mentioned use (Figure 3b). Roads that have asphalted or firmed gravelous sand surface are suitably located on sides connected with stripes of green vegetation. Fencing thoroughly connects to highway fencing. Surface is planted with grass, shrubs and trees of middle height. Successful solving of humidity rates is obvious from successful vegetation grows. During early hours visit of ecoducts was noted crossing of free roe-deers even with high noise load from highway. Also alleys and footprints in vegetation made by animals were found. This entire means that ecoducts perform their tasks.

Figure 4: Ecoduct on Highway A6

Same type of ecological bridge was used also on newly opened highway A6 (Nordost-Autobahn) in direction Wien – Bratislava. On segment with length 22 km are made 4 ecological bridges (Figure 4a) whereas one of them is combined. Similarly to objects on highway A4 was paid high attention to rigorous connection of highway and ecological object fencing and planning of surface (Figure 4b). Ecological bridges on highway A6 compared to bridges on highway A4 are not conveying traffic from one side to another.

4.3 Slovakia

In December 2008 was opened new segment of highway D1 that belongs to main traffic corridor of Slovakia in direction Bratislava – Žilina – Poprad – Košice. As part of newly opened segment is first ecological bridge and ecological tunnel in Slovakia.

Ecological bridge near municipality Jánovce (Figure 5) is designed as three joint parabolic curve made of glued wood lamellas girders with span 36 m and rise of arch 9 m and length in axis of road 16 m. Similar bridge is in Germany in Federal Republic Maklenburg – Front Pomerania near municipality Wilmshagen (Foglar and Křístek, 2006). It is very elegant structure emphasized with scene of High Tatras. For construction were used progressive materials and technologies (Brejcha, 2008). In contrast with ecological structures with straight-ground plan in Czech Republic and Austria, this has hyperbolic one.

Figure 5: Ecoduct on Highway D1 near Jánovce

Ecological bridge that fail to satisfy recommended minimal width of ecoduct 50 m (Bank *et al.*, 2002), convey over D1 highway field road with asphalt surface. Path is untypically for green bridge located in the centre and bordered with thin stripes of green vegetation. Part of object is wooden fencing simultaneously fulfilling function of sound barrier. Fencing thoroughly connects to highway fencing. On one side object border on forest on other side border on fields. The question is whether this ecological bridge will be used as migration path or only as bridge for field road.

Figure 6: Ecoduct on Highway D1 near Važec

Second new ecological object on highway D1 is ecological tunnel Lučivná (Figure 6), that lies near municipality Važec. It is excavated reinforced concrete tunnel with length 250 m made of two tunnel tubes. In transversal direction structure acts as dipole frame. It is very successful example of green bridges. Tunnel is from both sides connected to forest stand. The width is not only sufficient but also exceeded the recommended minimal width of ecoduct. Fencing thoroughly connects to highway fencing. There is no road or path on surface of tunnel. All access roads made during tunnel construction were demolished and planted with vegetation. Tunnel surface is planted with grass, bushes, coniferous and deciduous trees ordered in stripes. Successful solving of humidity rates is obvious from successful vegetation grows. Best documentation of good design of ecological tunnel was visit during which were noted many footprints (Figure 6b) belonging to roe and wapitis.

5. Concluding Remarks

Analysis of one of the basic pillars for long-term compatibility – ecological pillar with focus on preserving of sources and ecosystems in case of road structures has been implemented in this article. As part of these complex constructions are special structures – ecoducts, that are used for minimization of animal population fragmentation. For part of these structures i.e. green bridges are mentioned factors that influence their functionality as width, surface treatment, location, surface ordering, technical equipment, supplementary steps and loads. Ways of designing with introduction of their usability are documented on several examples of realized green bridges in several countries.

6. Acknowledgements

This article was elaborated as part of project No. 103/08/1278 and No. 103/09/2071 referring to the Grant Agency of Czech Republic and Research Intention MSM 0021630519.

7. References

Adamec, V., Machálek, P., Kupec, J., Holy, L., Šlachta, E., Hlaváček, J., Holoubek, I, and Tříska, J. (2006). "Výzkum zátěže životního prostředí z dopravy", výroční zpráva za rok 2005, Centrum dopravního výzkumu, Brno, Czech Republic.

Bank, F.G., Irwin, C. L., Evink, G. L., Gray, M. E., Hagood, S., Kinar, J. R., Levy, A., Paulson, D., Ruediger, B., Sauvajot, R. M., Scott, D. J., and White, P. (2002). "Wildlife Habitat Connectivity Across European Highways", Report No. FHWA-PL-02-011, Office of International Programs, Federal Highway Administration, US Department of Transport, Washington, USA.

Brejcha, V. (2008). "Ekochod z oblúkových lepených lamelových drevených nosníkov na stavbe diaľnice D1 Mengusovce – Jánovce III. etapa". *Silnice a železnice*, Vol. 3, No. 4, pp. 17-19, ISSN 1801-8220.

Brnušák, A., Císlerová, M., Dahinter, K., Křístek V., Voplakal, M., Kurth, H., and Lenner, R. (2003). "*Ekodukty*", Inženýrská akademie České republiky, Brno, Czech Republic.

Eurostat. (2008). Highway network density in selected countries for year 2004. Online at http://epp.eurostat.ec.europa.eu.

Foglar, M. (2008). "Ekologické mosty na dálnici A20 Lübeck - Štětín",*Udržitelná výstavba 4*, ČVUT, 2008, s. 105-110, ISBN 978-80-01-04250-2.

Foglar, M., and Křístek, V. (2006). "Ekodukt u Wilmshagenu - inovativní dřevěná konstrukce". *Silnice a železnice*, Vol. 1, No. 2, pp. 27-28, ISSN 1801-8220.

Hlaváč, V., and Anděl, P. (2008). "Mosty přes vodní toky – ekologické aspekty a požadavky". Metodická příručka. Krajský úřad kraje Vysočina, Agentura ochrany přírody a krajiny ČR, ISBN: 978-80-87051-40-5.

Mayer, J. and Foral, M. (2008). "Dočasná a trvalá opatření vyplývyjící ze zoologických průzkumů při výstavbě komunikací", *Sborník příspěvků Výzkum v ochraně přírody*, Editors: I.H. Tuf and V. Kostkan, UP Olomouc, Czech Republic, ISBN 978-80-7399-498-3.

Šikula, T. (2008). "Udržitelná výstavba dálnic – ekologické aspekty". *Sborník příspěvků Výzkum v ochraně přírody*, Editors: I.H. Tuf and V. Kostkan, UP Olomouc, Czech Republic, ISBN 978-80-7399-498-3.

Žák, J. (2008). "Technický migrační potenciál versus náklady", *Sborník příspěvků z mezinárodní conference Lidé, stavby a příroda 2008*, CERM s.r.o., Brno University of Technology, Brno, Czech Republic, ISBN 978-80-7004-600-3.