Ref: AF GR CON 21/2

Design of Terrestrial Wildlife Crossing System

1. Purpose

1.1 The purpose of this Practice Note is to provide technical guidance to relevant government departments, engineers, environmental consultants and other interested persons for design of crossing system for terrestrial wildlife as a mitigation measure for fragmentation by linear transport infrastructures. This Practice Note focuses on the design of Underpass.

1.2 This Practice Note only covers the design elements from ecological perspective while the engineering and cost constraints are project specific. The requirement and practicability of incorporating wildlife crossing system into the engineering design should be determined on a case by case basis by the project proponents.

2. Background

2.1 Construction of linear transport infrastructures across important ecological habitats always implies an adverse impact on wildlife. The infrastructures dissect continuous habitats into smaller and isolated patches (**habitat fragmentation**). The higher edge to interior ratios thus increases the level of disturbance effect and reduces the amount of core habitat. Consequently, the habitat quality will be degraded for a much wider zone than the actual physical loss in area that is taken up by of the footprint of the infrastructure (**edge effect**).

2.2 **Barrier effect** occurs when wildlife are unable to cross the road due to physical barriers (e.g. the road surface, ditches, fences and embankments), avoid the area of the roadways (**road avoidance**), or are killed on the road (**roadkills**). Barrier effect, compounds those of habitat fragmentation and isolation, cause impacts on wildlife from individual to population levels (Figure 1).

2.3 Physical barriers may divide wildlife populations into smaller, more isolated units. Individuals in such smaller populations may not be able to interact with populations elsewhere and be more susceptible to genetic deterioration through loss of genetic variation by inbreeding. Over time, they may face local extinction from environmental variability and natural catastrophes. In certain situations, the physical barriers may even block the habitual routes to feeding or breeding grounds of some species (e.g. the frogs cannot reach the ponds where they used to breed), and hence the affected species would not be able to complete their life cycles. However, not all kinds of wildlife are equally susceptible to barrier effect. In general, non-flying terrestrial animals, e.g. mammals, amphibians and reptiles, are more susceptible to barrier effect while birds would have smaller impact because of their relatively high mobility.

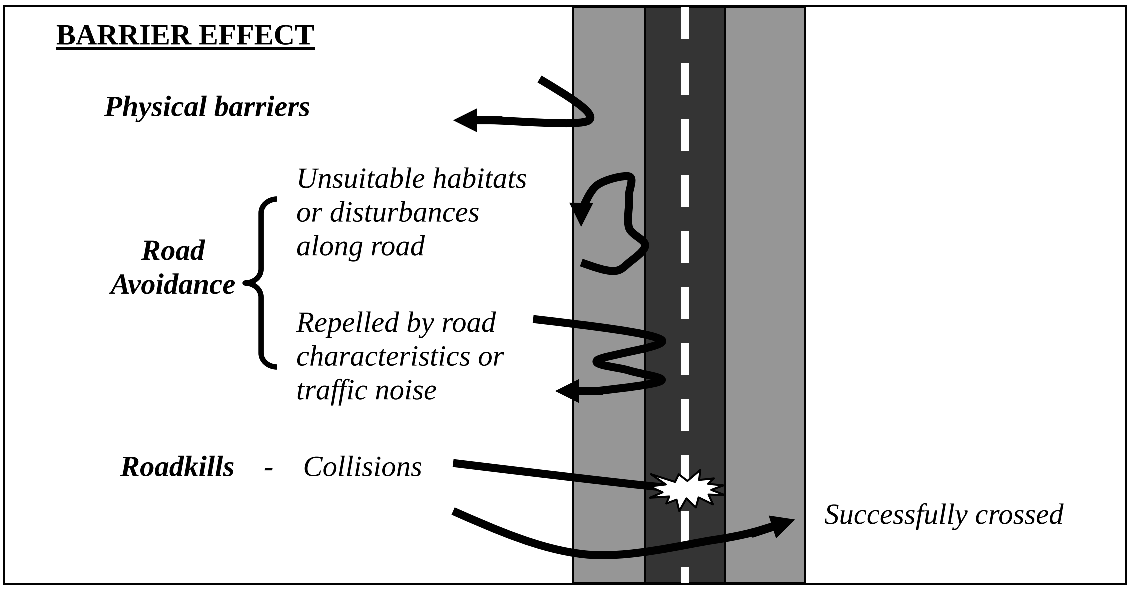

Figure 1 Barrier effect of a road results from a combination of physical hindrance, disturbance, repellence and mortality etc. (modified after Seiler, 2001).

2.4 The most effective measure to avoid barrier effect and habitat fragmentation of any proposed linear infrastructures is selecting the route of the structure to avoid important ecological habitats (i.e. alternative alignment). Through baseline surveys of the subject area, ecological information of the area such as abundance of wildlife and major wildlife movement corridors should be collected, and hence the locations of potential wildlife-traffic conflict points should be identified.[1] All such locations should be taken into consideration and avoided as far as practicable during the route selection process.

2.5 Should habitat fragmentation be unavoidable and the ecological information reveals that there are potential problems of wildlife-traffic conflict in operation phase (e.g. a high density of wildlife movement in the subject area, and the species involved are susceptible to the barrier effect created), appropriate designs of the infrastructures and mitigation measures should be recommended to minimize the ecological impacts of the development. For instance, measures should be implemented to make the roads more permeable for wildlife by offering safe alternative ways of crossing.

3. Wildlife crossings

3.1 Wildlife crossings is the collective term referring to the artificial links constructed above roadways (overpasses) or underneath roadways (underpasses) to facilitate safe passage of wildlife through fragmented habitats, and hence re-establish habitat connectivity across the infrastructure barriers (i.e. de-fragmentation).

3.2 **Overpass** structures, also called ecoducts or green bridges, are usually wider on each end and narrower in the centre. A soil layer is added on the surface of the overpasses to allow growth of herbaceous vegetation, shrubs and even small trees for attracting wildlife. However, overpasses are often large in scale and expensive to construct, and should only be used for important migration corridors between significant habitats.

[1] The Environmental Impact Assessment Ordinance Guidance Notes No.7/2002 on Ecological Baseline Survey for Ecological Assessment and No. 10/2004 on Methodologies for Terrestrial and Freshwater Ecological Baseline Surveys provide the general guidelines for conducting an ecological baseline survey and introduce some methodologies in conducting such surveys respectively.

3.3 **Underpass** structures can be in form of bridge underpasses when roads are above open fields, cross streams or other roads (e.g. viaduct and open-span bridge) and can be used to provide a relatively unconfined passageway for wildlife. Underpass can also be in form of tunnel or box culvert (Figure 2). Tunnels and culverts are usually made of steel or concrete material and are mostly engineered to allow water flow or traffic under road structure. However, specially designed tunnels and culverts could also facilitate wildlife movement and habitat connectivity.

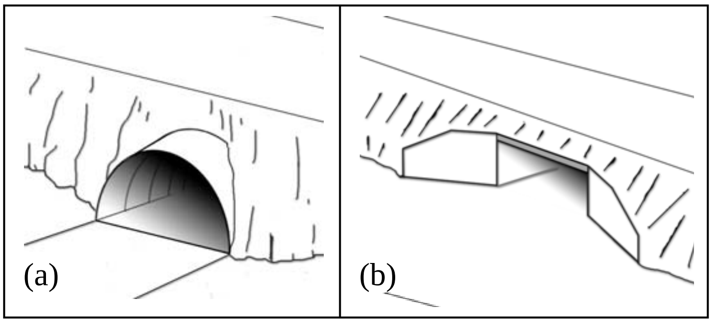

Figure 2. Basic design of common underpasses (a) tunnel and (b) box culvert.

3.4 Modification on the design of tunnels for traffic or pedestrians can also be applied for providing wildlife passage. Tree stumps and other suitable substrates could be placed along one side of the tunnel to promote wildlife usage but suitable screens or partitions should be established between the wildlife passage and the traffic line.

3.5 Using crossing structures to mitigate the negative impacts of roadways or railway on wildlife is a relatively new concept in Hong Kong. There have been a few ecological impact assessments which propose wildlife crossing as mitigation measures to barrier effects. The first purposely constructed wildlife crossing in Hong Kong is a concrete tunnel beneath Route 3 at the Ting Kau end of Tai Lam Tunnel of Route 3. The structure is about 70 m in length and 1.8 m in internal diameter. It aims to facilitate the movement of Masked Palm Civet (*Paguma larvata*) and Red Muntjac (*Muntiacus muntjac*) (Figure 3). However, recent monitoring results demonstrated that the wildlife tunnel was very low in usage which was attributed to the design of the structure (Shek, 2006). A few more local examples are illustrated in section 5.

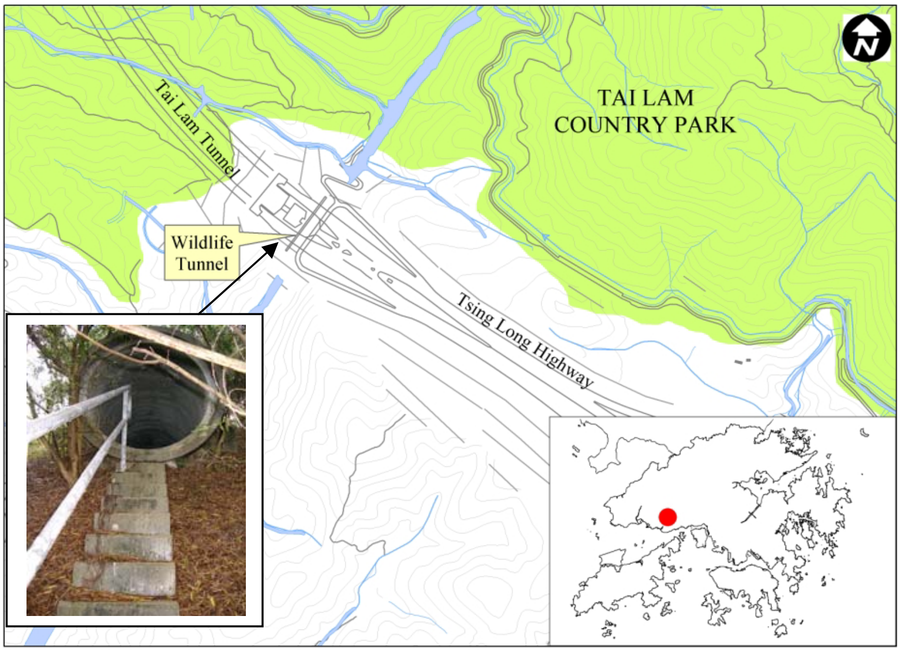

Figure 3. The first purposely constructed wildlife underpass in Hong Kong crossing beneath Route 3.

4. Design elements of underpass structures

4.1 While wildlife underpass can be of many different structures, shapes and sizes, the most fundamental issue in the design depends on the target species to be determined on a case by case basis. It is important to understand the distribution, abundance, ecological and behavioural need of the target species. There are however some basic design elements that make the structures more permeable for all wildlife. The design elements for success include placement, wildlife accessibility, structure design (e.g. size, substrate, vegetative cover, human disturbance, temperature, light and moisture), fencing mechanism, and on-going maintenance and monitoring which are discussed in the following paragraphs.

Placement

4.2 Proper placement is the key factor of an effective wildlife underpass. The most appropriate location of an underpass should be near the impacted wildlife movement corridor, and the road sections where roadkills are likely. Suitable habitats should be present on both sides of the road in the proximity of the underpass and be protected in the future. Otherwise, the underpass would become unsuitable for wildlife or even a mortality sink.

Accessibility

4.3 An underpass structure would be of no use if it is inaccessible to the target species. The accessibility of an underpass is subject to various physical factors, such as the steepness of underpass itself or the slope leading to the structure, and the structure entrance height above the ground surface. For instance, a perched pipe or standing water at the entrance of an underpass will render the structure less accessible to many animals. As such, appropriate design around the structure entrances should be incorporated into the structure design to ensure the accessibility.

4.4 Underpasses are more effective in facilitating wildlife passage and preventing road kill when the option of utilizing the underpasses is more appealing to the target species than the option of crossing the roadway. To encourage wildlife to approach an underpass, the area in proximity to the entrance should be unlit and free from human disturbance. Suitable habitat of dense vegetation surrounding and leading up to the underpass entrance can provide smaller animals with protection by concealing them from predators.

Openness ratio

4.5 Dimension of a wildlife underpass is determined by the road width, the structure type, and the functional groups of target species. Large and medium mammals that use their eyesight to avoid predation usually prefer open vistas, where a relatively large openness ratio of the underpass may be more important than the absolute size.

$$\text{Openness Ratio} = \frac{\text{Cross-sectional area of underpass opening}}{\text{Length of underpass}}$$

4.6 Underpasses may be designed by adjusting the size of the structure proportionally to its length to make the aperture appearance large enough that animals can see the opposite end of an underpass, and hence consider that it is safe to enter. On the contrary, small mammals, amphibians and reptiles generally prefer underpasses with smaller cross-sectional areas.

Substrate and moisture

4.7 In general, an underpass would look appealing to wildlife if its internal habitat resembles ambient conditions such as substrate, moisture, light, temperature and noise. An effective underpass should maintain habitat continuity by providing, throughout the entire length of the structure, an appropriate natural substrate that is consistent with the external surroundings on either side of the underpass.

4.8 Some small mammals, amphibians and reptiles use vegetation or topography to hide themselves from predators and the dying heat of the sun. These animals would feel more secure entering an underpass if it provides sufficient cover, which could be created by placement of piles of gravels or vegetative debris such as tree stumps, hollow logs and small bush around the structure and along the edge of its interior walls. These covers could also create a moist environment generally favoured by amphibians and riparian reptiles.

Ledge

4.9 While moist substrate is important for amphibians and riparian reptiles, standing water within underpasses would deter many animals from entering the structures. As such, underpasses that accommodate amphibians and riparian reptiles should maintain moist substrate but at the same time provide a dry ledge along the entire length of one or both interior walls of the structure (Figure 4). The ledge allows other wildlife to pass through the underpass when it is filled with water. Again, the ledge should be covered with natural substrate and hiding cover consistent with the external surroundings and is wide enough to accommodate the target species.

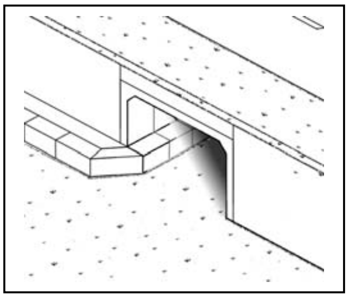

Figure 4. Box culvert with ledge for wildlife passage

Interior walls

4.10 The interior walls of an underpass could be modified to mimic a natural corridor. For instance, the interior walls of the structure could be painted dark at the bottom but white above to resemble natural conditions. The wall surfaces could be made roughly textured so as to reduce unnatural sounds such as pattering when wildlife moves through the underpass.

Lighting and temperature

4.11 There have been evidences that artificial light deters animals from utilizing an underpass. Ambient light conditions inside an underpass could be maintained by providing an entrance of larger cross-sectional area (i.e. larger openness ratio) or by incorporating an open-top system at certain portions of the underpass (e.g. light shafts in the central divider as in Figure 5). The open-top system would also allow more air flow within the underpass which could reduce the temperature difference between inside and outside of the structure. Nonetheless, covers such as piles of rocks or vegetation debris which create a darker environment should be placed within the structures if small mammals, amphibians and reptiles are also the target groups.

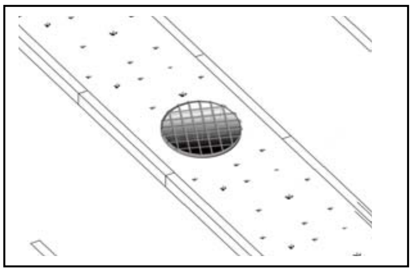

Figure 5. Circular light shaft in the central divider

5. Fencing mechanism

5.1 An effective wildlife crossing system should be constituted of properly designed crossing structures as discussed above together with a fencing mechanism. Barrier fence along the roadways in both directions of the crossing structures is a vital feature of a crossing system. It compliments the crossing structures by keeping wildlife off the road to avoid roadkills while guiding them to the crossing structures. In the project “Improvement to Tung Chung Road between Lung Tseng Tau and Cheung Sha” on Lantau Island, a fencing mechanism is introduced to keep small mammals and amphibians, particularly the Romer’s Tree Frogs (*Philautus romeri*), off the road as well as the U-shaped channels while guiding them to the three underpasses constructed to mitigate the barrier effect caused by the road works (Figure 6).

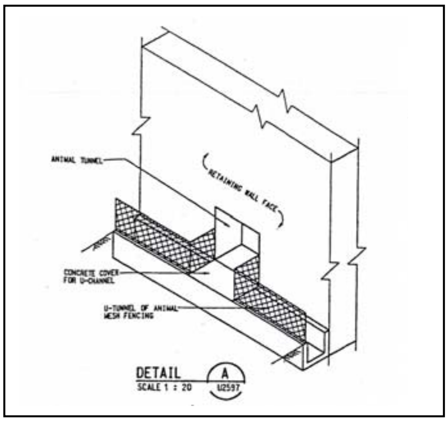

Figure 6. Fencing along the improved Tung Chung Road between Lung Tseng Tau and Cheung Sha, Lantau Island (after Mott Connell, 2003).

Size and material

5.2 Height, mesh size and material of the barrier fence are the basic but important considerations in designing an effective fencing mechanism. There is no effective standard for its sizing as it varies with the target species. In general, fence height may range from 300 mm for amphibians to 2,000 mm or more for large mammals. Longitudinally, the fencing should extend far enough on both side of an underpass to reduce roadkills and guide the target species towards the underpass.

5.3 Fencing material should be chosen to avoid penetration by the target species. The commonly used materials include chain link, plastic vinyl, concrete, galvanized tin and aluminum flashing. As some animals such as small mammals, amphibians and reptiles may be able to pass through the fence, wire fence of fine mesh size could be applied to the bottom one-third to one half of a large-mesh fence (Figure 7). In the Tung Chung Road improvement project, a very fine aluminum mesh (5x9.5 mm) of 300 mm in height is used to prevent the tiny Romer’s Tree Frog from passing through the fence (Figure 8).

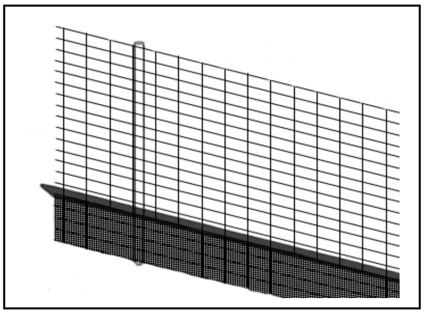

Figure 7. A double fence consisting a high, large-mesh fence and a low, fine-mesh fence. The fine-mesh fence is bent over at the top to stop animals climbing over it.

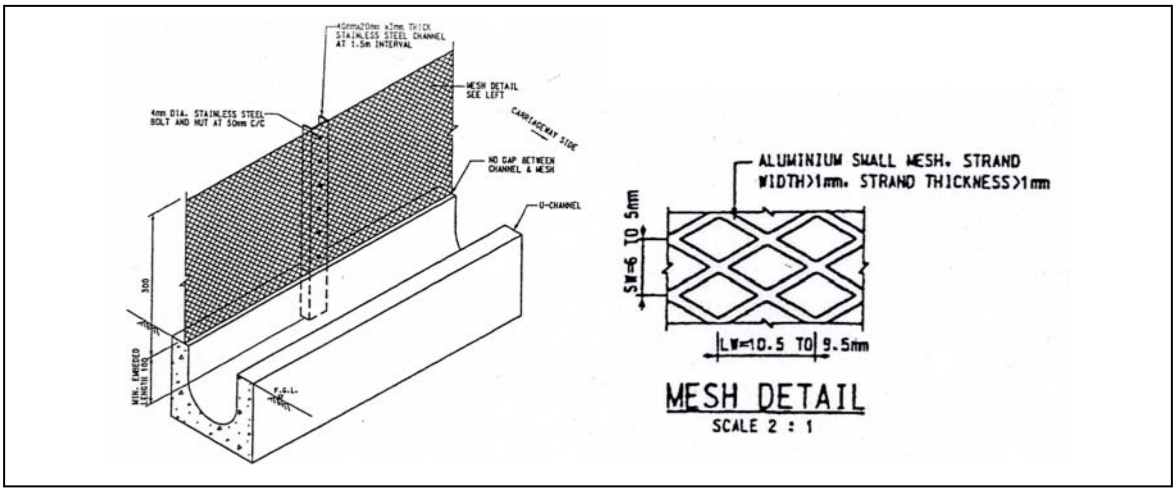

Figure 8. Fencing along the improved Tung Chung Road between Lung Tseng Tau and Cheung Sha, Lantau Island (after Mott Connell, 2003).

5.4 In the project of “Lok Ma Chau Terminus and Associated Works of the Kowloon-Canton Railway (KCR) East Rail Extensions”, a wildlife underpass linking the fishponds on both sides of the railway is proposed to serve as a corridor for Eurasian Otter (*Lutra lutra*) inhabiting in the area. The underpass consists of a tunnel 800mm in diameter suitable for use by Eurasian Otter or similar-sized mammals. A 300mm gently sloping grasscrete ledge connecting the tunnel with the adjacent nullah would provide a wildlife corridor suitable for Eurasian Otter which typically uses the sides of channels as movement corridors. At the center of the tunnel, a drain is provided to prevent water logging which would hinders the use of the underpass by the animals. Chain link fence of large mesh (40 x 40 mm) of 1,125 mm in height and an inclined top is adopted as the fencing mechanism (Figure 9).

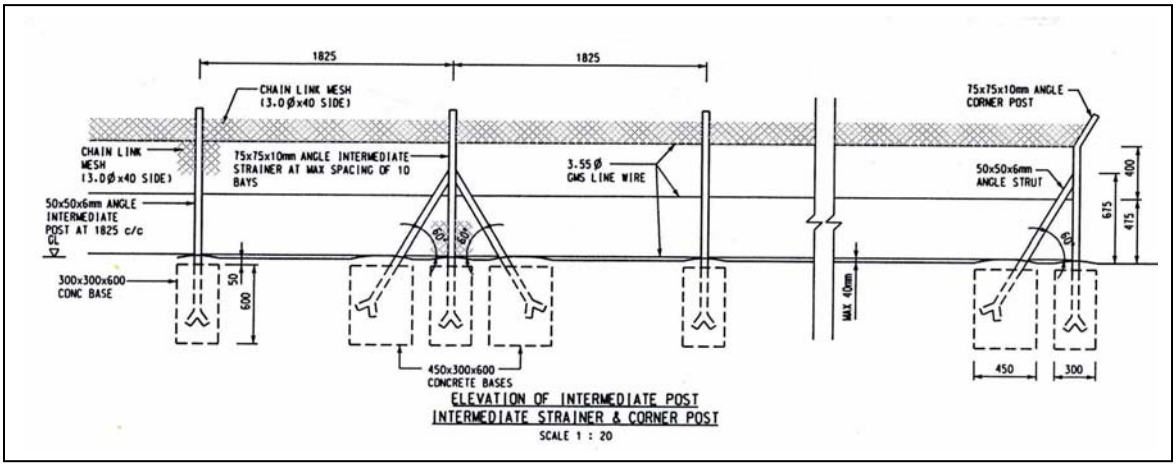

Figure 9. General design of fencing connected to the wildlife underpass in Lok Ma Chau for the project of KCR Lok Ma Chau Terminus and associated works (after Mott Connell, 2004).

Fence top and bottom

5.5 To discourage animals such as reptiles from climbing over the fence, the top of chain link fencing should have inverted net at an angle of 30 to 90 degrees (Figure 10). For concrete walls, lipped walls could be used to prevent animals such as snakes and frogs that manage to scale the smooth wall surface from climbing over the wall (Figure 11).

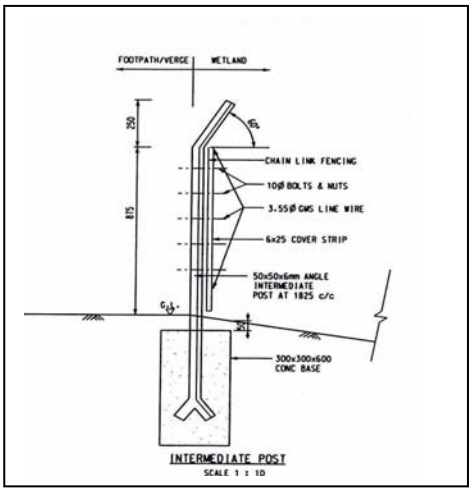

Figure 10. Detailed design of the top and bottom of the fencing constructed for the project of Lok Ma Chau Terminus and associated works (after Mott Connell, 2004).

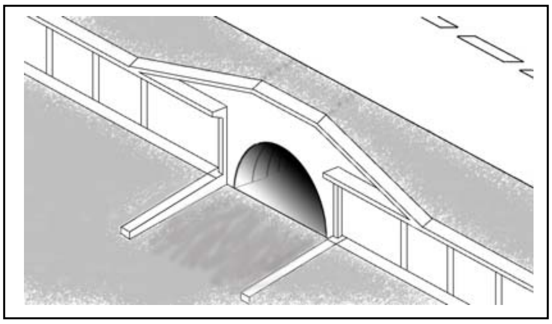

Figure 11. A tunnel underpass with lipped concrete wall for amphibians and reptiles.

5.6 Vegetation such as trees and large bushes that are adjacent to the fence should be kept to the minimum, as they could act as “natural ladders” which facilitate animals climbing over the fence, and hence lessen the effectiveness of the fencing mechanism (Figure 12).

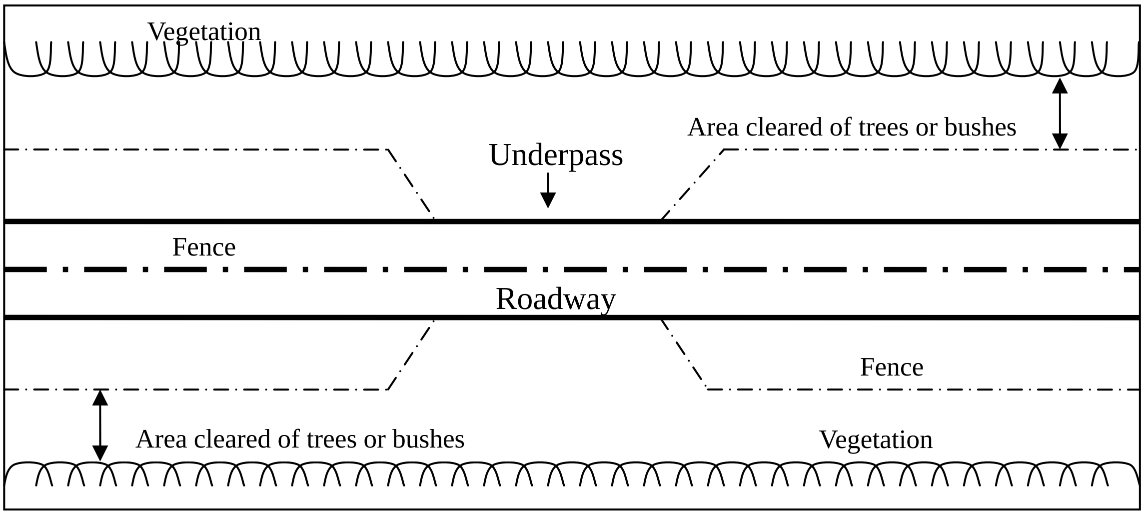

Figure 12. General design of fencing mechanism for a wildlife underpass (modified after USDA Forest Service, 2005).

5.7 Fencing for small mammals, amphibians and reptiles should be specifically designed to prevent the animals from digging under the fence. If the fencing is installed on natural substrate, the fence should be buried to increase stability and at the same time prevent animals from digging under the fence. The depth of the buried section depends on the types of the target species.

__Escape ramps__

5.8 While underpasses provide connectivity underneath the roads, exits along the fencing should be provided to allow wildlife trapped on the roadway to pass through the fencing, especially when extensive fencing is installed on only one side of underpasses. Common examples of exits from the fencing include one-way gates or escape ramps at regular intervals (Figure 13).

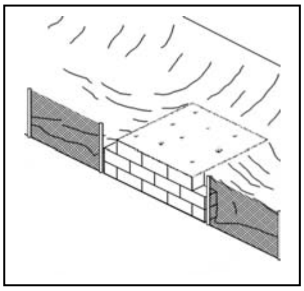

Figure 13. An escape ramp along fencing.

5.9 In areas where amphibians are of particular concern, ramps or breaks in kerbs and drains along the roads could prevent entrapment of these animals. In the Tung Chung Road improvement project, amphibian and reptile escape ramps are incorporated in the U-shaped channels which are 200 to 300 mm deep along the road. The ramps extend 100 mm from the channel wall and face both upstream and downstream. They have a cross-fall angle of 5^o dipping into wall of channel to prevent the amphibian and reptile from falling back into the channels, and rise from floor to top of channel at a gentle slope of 10^o (Figure 14).

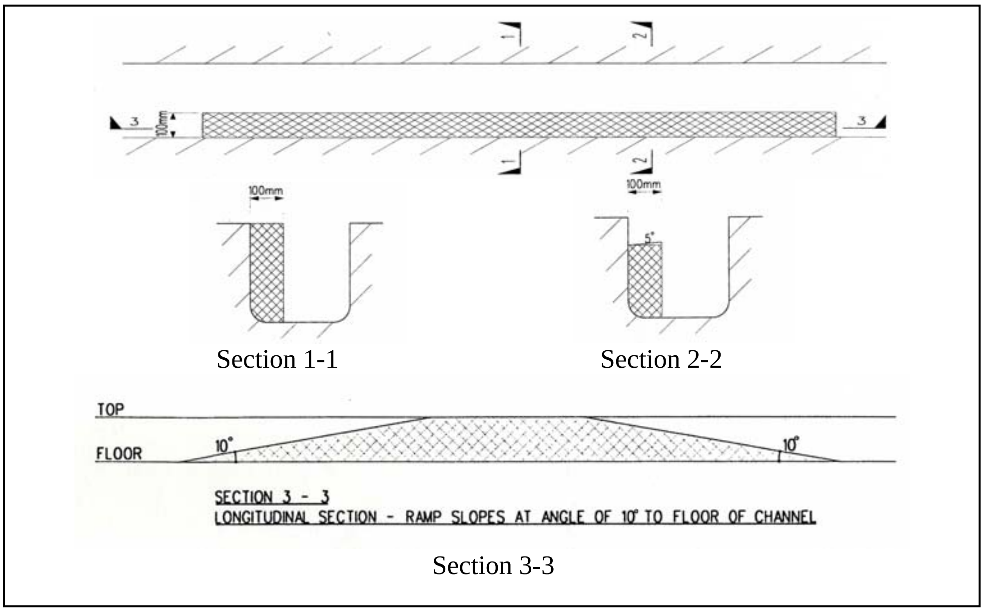

Figure 14. Design of amphibian and reptile escape ramps in U-shaped channels along the improved Tung Chung Road between Lung Tseng Tau and Cheung Sha (after Mouchel, 2002).

6. Consideration for different wildlife groups

6.1 The ecology and behaviour of the target species should be taken into account during the structure design as elements of the design are usually specific to the functional group of the targeted species. For example, a moist substrate is essential for amphibians and reptiles, while mammals are generally indifferent to the substrate surface. On the other hand, openness ratio is important for large mammals but not for amphibians and reptiles. For semi-aquatic species (e.g. Otter), crossing with an appropriate water depth is recommended.

6.2 The terrestrial wildlife groups which are susceptible to barrier effects of infrastructure include mammals (e.g. Masked Palm Civet and Eurasian Otter), reptiles and amphibians (e.g. Romer’s Tree Frogs). These animals can be generally classified into four functional groups, namely large mammals, medium mammals, small mammals and amphibians/reptiles. To accommodate the varying needs of these functional groups, design guidelines that are specific to these groups are suggested in Table 1 for general reference.

Table 1. Specific design guidelines of wildlife underpasses for animal functional groups
(√ - Best option **O** - Minimum requirement n.a. - Not Applicable)

Animal Group	Large Mammals	Medium Mammals	Small Mammals	Amphibians / Reptiles
Head-to-body length	> 60 cm	30 – 60 cm	< 30 cm	-
Local Examples	Red Muntjac (*Muntiacus muntjac*) Masked Palm Civet (*Paguma larvata*) Leopard Cat (*Prionailurus bengalensis*) Eurasian Otter (*Lutra lutra*)	Chinese Pangolin (*Manis pentadactyla*) East Asian Porcupine (*Hystrix brachyura*) Small Asian Mongoose (*Herpestes javanicus*)	Chestnut Spiny Rat (*Niviventer fulvescens*) Indochinese Forest Rat (*Rattus andamanensis*) Musk Shrew (*Suncus murinus*)	Amphibian & riparian reptiles Frogs, toads, turtles, some snakes Upland reptiles Lizards and some snakes
Structure Type				
Pipe culvert	**O**	**O**	√	√
Box culvert	**O**	**O**	√	√
Bridge underpass	√	√	**O**	**O**
Structure Design Guidelines				
Openness Ratio	**O** (> 0.75)	**O** (> 0.4)	n.a.	n.a.
Structure Dimension (opening)	n.a.	n.a.	0.2 - 0.4 sq. m.	0.2 – 0.8 sq. m.
Structure Height	> 180 cm	> 100 cm	> 30 cm	> 30 cm
Substrate Moisture	n.a.	n.a.	n.a.	n.a. (upland reptiles) **O** (amphibian/ riparian reptiles)

7. Maintenance and Monitoring

7.1 Maintenance of wildlife underpasses and the associated structures is required to ensure their effectiveness over time. Maintenance of an underpass include clearing debris or other impediments to movement through the structure, replacing shelters such as piles of gravels or vegetative debris and maintaining adjacent habitat to facilitate wildlife movement to the underpass. The structure stability and sign of erosion surrounding or inside the underpass should also be checked for necessary maintenance.

7.2 Maintenance requirement of a fencing mechanism depends on the type of fencing. While short concrete walls provide relatively maintenance-free barriers for small mammals, amphibians and reptiles, wire fencing installed on natural substrate may need regular checking to ensure that the fencing is properly buried.

7.3 Where warranted, monitoring programme should be developed to assess the effectiveness of the wildlife underpasses. Evaluation of the findings would provide valuable information for designing new underpasses in future projects. Effectiveness of an underpass can be indicated by the signs of wildlife usage. Besides the traditional methods of identifying animal dung and footprints found inside the underpasses (e.g. by track plates filled with soot or gypsum powder or tracking beds with sand or ink), recent technology such as automatic camera and video have been developed to monitor wildlife uses of underpasses.

7.4 **Automatic camera and video** mounted inside underpasses are evolving technologies which make it possible to capture images or even observe the behaviour of the wildlife while utilizing the structures. They are proved effective in documenting animal use of larger underpasses such as bridges or box culverts. Automatic camera was installed inside the wildlife underpass crossing underneath Route 3, and utilization of the tunnel by Masked Palm Civets was detected (Figures 15 &16).

Figure 15. Automatic camera was installed inside the underpass crossing underneath the Route 3 to monitor the wildlife uses of the tunnel.

Figure 16. Picture of a Masked Palm Civet captured by automatic camera when it utilizes the wildlife underpass underneath Route 3.

8. Enquires

8.1 Enquiries on this Practice Note should be addressed to the Senior Conservation Officer (Technical Services) at mailbox@afcd.gov.hk.

Agriculture, Fisheries and Conservation Department
October 2006

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