Agriculture, Fisheries and Conservation Department
Conservation Branch

Nature Conservation Practice Note No. 04

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 parties on the design of crossing system for terrestrial wildlife to mitigate the potential impacts arising from habitat fragmentation due to infrastructure projects.

1.2 This Practice Note provides design considerations from the ecological perspective only. Other requirements and constraints such as engineering feasibility and costs are beyond the scope of this Practice Note.

2. Background

2.1 Infrastructures particularly those of a linear dimension (e.g. roads) have potential adverse impacts to wildlife especially when they are constructed across important ecological habitats. Habitat fragmentation occurs when the infrastructures dissect continuous habitats into smaller and isolated patches (Figure 1a). Besides the direct loss of core habitats, indirect impact in form of edge effect may result from increased level of disturbance caused by the higher edge to interior ratio. Consequently, the habitat quality would be degraded over a much wider zone than the actual physical loss in area that is taken up by the footprint of the infrastructures (Kirby, 1995).

2.2 Physical barriers resulting from linear infrastructures may divide wildlife populations into smaller and more isolated units. Individuals in such smaller populations may not be able to interact with populations elsewhere and be more susceptible to genetic deterioration (Gerlach and Musolf, 2000; Frankham et al., 2017).

2.3 Apart from physical blockage of wildlife passage (e.g. hard-paved road surface, ditches, fences and embankments) and risk of road kills, barrier effect could also result from behaviourial changes, e.g. wildlife avoiding the area of the roadways due to traffic, noise, light or perceived inhospitable conditions. Barrier effect, together with habitat fragmentation and isolation, cause impacts on wildlife from individual to population levels. Not all kinds of wildlife are however equally susceptible to barrier effect. In general, non-flying terrestrial animals, e.g. amphibians and reptiles, are more susceptible to barrier effect than animals with relatively high mobility, such as birds.

2.4 The most effective measure to avoid barrier effect and habitat fragmentation of any proposed linear infrastructure is selecting the route of the structure to avoid important ecological habitats (Figure 1b). Through baseline surveys of the subject area, ecological information of the area such as abundance of wildlife and major wildlife movement corridors could be collected, and hence facilitating the identification of locations of potential wildlife-traffic conflicts. Such locations should be avoided as far as practicable during the alignment selection process.

2.5 Should habitat fragmentation be unavoidable and the ecological information reveals that there are potential problems of wildlife-traffic conflict during operation phase, appropriate design of the infrastructure to mitigate the ecological impacts should be considered. Examples include provision of linear corridors (overpasses/underpasses) and stepping stones to assist wildlife to traverse the landscape (Figure 1c), or by buffering the high-quality habitat patches to control disturbance from adjacent development. Compensation for the loss of wildlife habitat by re-creating a replacement nearby could also be adopted as a mitigation measure (Figure 1d).

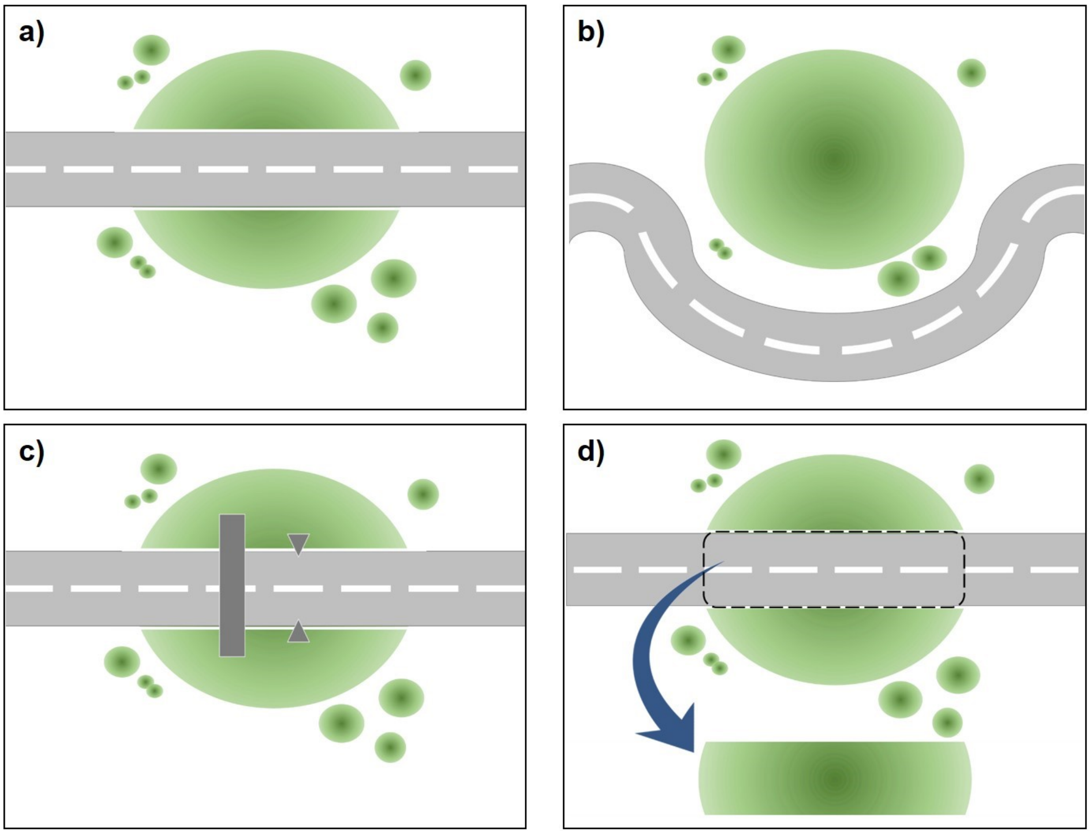


Figure 1. Schematic diagram showing different strategies of road construction across an ecological habitat. (a) Direct construction across the habitat causes habitat fragmentation; (b) Adjusting the road alignment to avoid habitat fragmentation; (c) Providing linear corridors for wildlife to traverse the road; and (d) Compensating the habitat loss by creation of replacement habitat nearby (after Clevenger and Huijser, 2011).

3. Types of wildlife crossings

3.1 Wildlife crossings are one of the most widely adopted measures to mitigate the potential ecological impact from linear infrastructures. They aim to improve the permeability of the infrastructures to wildlife by facilitating wildlife movement through the fragmented habitats. Wildlife crossings generally consist of artificial links constructed above (overpasses) or underneath the infrastructures (underpasses).

3.2 Overpasses, often in the form of ecoducts or green bridges, mainly serve to provide corridors for large mammals when significant habitats with high species diversity (e.g. nature reserve, forests, etc.) are bisected by linear infrastructures. Recent studies show that overpasses not only support the movement of a wide variety of wildlife, but also serve as permanent habitats themselves for the smaller species (McGregor et al., 2015). In Southeast Asia, however, examples of overpasses appears to be limited. Nonetheless, the Eco-Link@BKE (Bukit Timah Expressway) built in Singapore in 2013 (Figure 2) presented a good example. It connects primary forest remnants of two nature reserves, i.e. Bukit Timah Reserve and the Central Catchment Area, and enables native animals including flying squirrels, monitor lizards, palm civets, pangolins, other small mammals, birds, insects and snakes to move across the reserves. It is also a spot for public educational tours (Singapore National Parks Board, 2018).

Figure 2. Eco-Link@BKE in Singapore (Singapore National Parks Board, 2018).

3.3 Existing structures such as bridges can also provide overpasses for wildlife movement while maintaining their ordinary functions for pedestrians, cyclists or vehicles, etc. In Taiwan, an animal passage was constructed on a vehicular bridge of 7.5 m in width with low traffic density near Tongsiao in 2013. One third of the width of the bridge (2.5 m) was modified to a passage equipped with escape ramps and green fences for wildlife use, while the remaining 5 m wide road is still sufficient for vehicle passage (Figure 3). Leopard cats were recorded using the overpass shortly after the modification work (Academia Sinica Center for Digital Cultures, 2018).

Figure 3. Animal passage constructed on an existing vehicular bridge in Taiwan (Academia Sinica Center for Digital Cultures, 2018)

3.4 Underpasses are usually in form of a tunnel or box culvert (Figure 4). Tunnels and culverts could be made of steel or concrete materials but specially designed ones would better improve the wildlife movement and habitat connectivity. Sufficient cover and protection over the openings could also enhance the utility of animals (small mammals in particular) in these structure (Clevenger and Huijser, 2011).

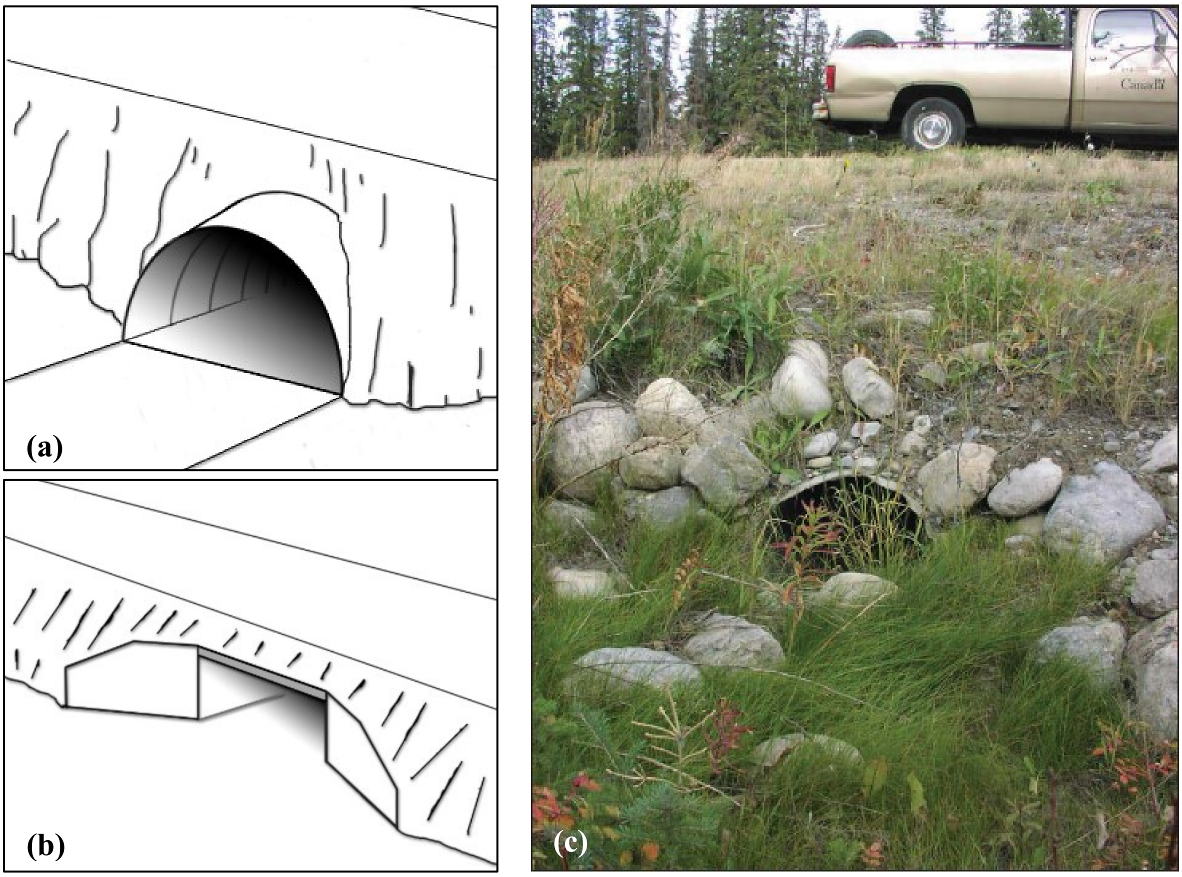
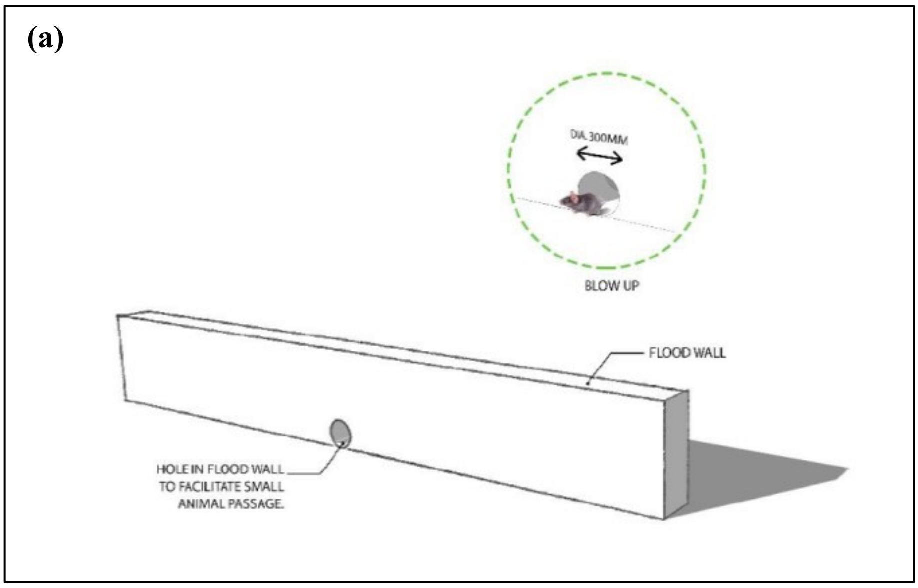


Figure 4. Schematic diagram of the basic design of common underpasses of (a) pipe culvert and (b) box culvert. (c) An example of mammal underpass with dense cover of vegetation (after Clevenger and Huijser, 2011).

3.5 Besides underpasses and overpasses, other animal passes, such as holes and pathways, could also be considered for animals that are isolated by vertical barriers like fences and floodwall structure. Site boundary fence was constructed to prevent access and disturbance at Lok Ma Chau Ecological Enhancement Area. In order to minimize the impact on connectivity of the surrounding areas, mammal passes with approximately 20 cm in diameter were installed at ground level for the movement of Eurasian Otter (Asia Ecological Consultants, 2017) (Figure 5).

Figure 5. Mammal pass designed for Eurasian Otter at Lok Ma Chau Ecological Enhancement Area.

3.6 Animal passes for floodwall structure, like holes or ladders for small animals to climb over, have been proposed for the Proposed Improvement Works at San Tin Eastern Main Channel in the project "Drainage Improvement Works at North District – Package B – Investigation" (Mott MacDonald, 2018) (Figure 6).



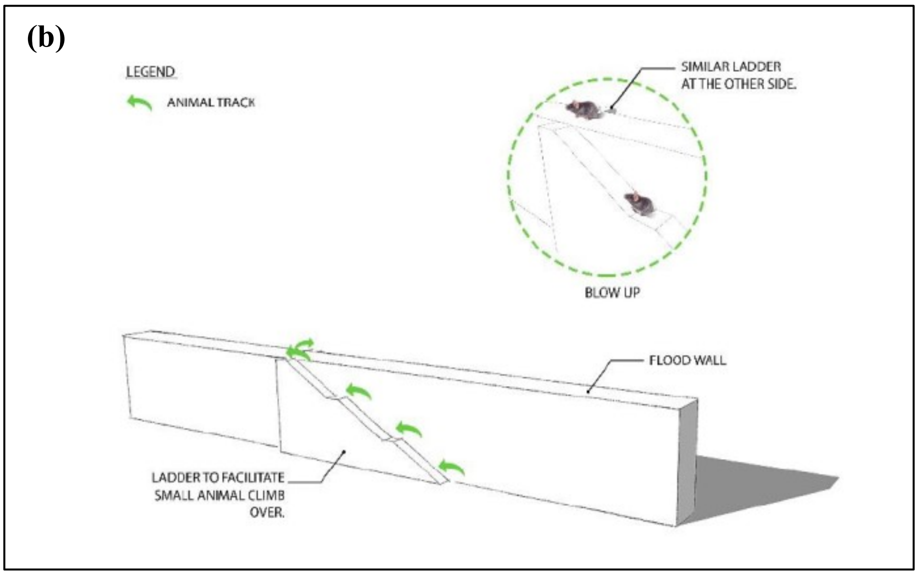


Figure 6. Indicative diagram of the (a) hole and (b) ladder on animal passes for floodwall structure (after Mott MacDonald 2018).

4. Design considerations of wildlife crossings

4.1 Proper placement is the key factor of an effective wildlife crossing (including both overpass and underpass) and should be determined on a case-by-case basis. Wildlife crossings should preferably be constructed near the impacted wildlife movement corridor. Suitable habitats should be properly managed and protected on both sides of the infrastructures in the proximity of the wildlife crossing.

4.2 While wildlife crossings can be of many different structures, shapes and sizes, the most fundamental issue in the design depends on the target species (Lesbarreres and Fahrig, 2012). It is important to have an understanding on the distribution, abundance, ecological and behavioural needs 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, accessibility, structure design (e.g. size, substrate, vegetative cover, human disturbance, temperature, light and moisture), fencing mechanism, on-going maintenance and monitoring, which are discussed in the following paragraphs.

Accessibility

4.3 A wildlife crossing would be of no use if it is inaccessible to the target species. Accessibility is subject to various physical factors, such as the steepness of the crossing itself or the slope leading to the structure, and the level difference between the structure entrance and the surrounding habitats. 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 entrance should be incorporated into the structure design to ensure its accessibility.

4.4 For roads that are constructed at grade, 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 use, the area near 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.

Dimension and Openness ratio

4.5 One critical factor determining the success of a wildlife underpass is its dimension, which is determined by the road width, the structure type, and the requirements of target species. For example, with a 1.8 m diameter concrete tunnel (Figure 7) constructed beneath Route 3, mammals such as Masked Palm Civets (*Paguma larvata*, Figure 8a) and Leopard Cats (*Prionailurus bengalensis*, Figure 8b) have been recorded in this underpass. On the other hand, the minimum structure height and the optimal opening dimension of wildlife underpasses for amphibians and reptiles should be less than that for large mammals.

Figure 7. The first wildlife underpass in Hong Kong beneath Route 3 was constructed in 1998.

Figure 8. (a) Two Masked Palm Civets and (b) a Leopard Cat utilizing the wildlife underpass underneath Route 3.

4.6 Large mammals that use their eyesight to avoid predation usually prefer open vistas, where a relatively large openness ratio (*Equation 1)* of the underpass may be more important than the absolute size. However, the relationship between openness ratio and underpass performance may be species-specific and time-dependent, hence it would be difficult to assign a particular ratio for different animal groups.

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

4.7 Underpasses may be designed by adjusting the size of the structure proportionally to its length so that animals can see the opposite end of an underpass, and hence consider it safe to enter. Small mammals, amphibians and reptiles generally require underpasses with smaller cross-sectional areas.

Substrate and moisture

4.8 In general, a wildlife crossing would look appealing to wildlife if its internal environment resembles that of the surroundings. An effective crossing should maintain habitat continuity by providing, throughout its entire length, an appropriate natural substrate that is consistent with the external surroundings on either side of the crossing (Beben, 2012). For underpasses, factors such as moisture, light, temperature and noise may also need to be considered.

4.9 Some small mammals, amphibians and reptiles use vegetation or topography to hide themselves from predators and the heat of the sun. Provision of sufficient cover in the crossing, by placement of piles of gravels or vegetative debris such as tree stumps, hollow logs and small bush is encouraged (Yanes et al., 1995).

Ledge

4.10 Underpasses are prone to flooding and accumulation of water pools which may deter animals from entering the crossing. As such, that design of underpasses that target at water dependent species should address the need to maintain moist substrate and at the same time provide a dry ledge along the entire length of one or both interior walls of the crossing (Figure 9). The ledge should be constructed above the high-water mark to allow the passage of other wildlife through the underpass when it is filled with water (Foresman, 2003; Villalva et al., 2013). The ledge should be made of sturdy materials such as galvanized steel, concrete or wooden boards instead of corrugated metal. It should also be covered with natural substrate and hiding cover consistent with the external surroundings and is wide enough to accommodate the target species.

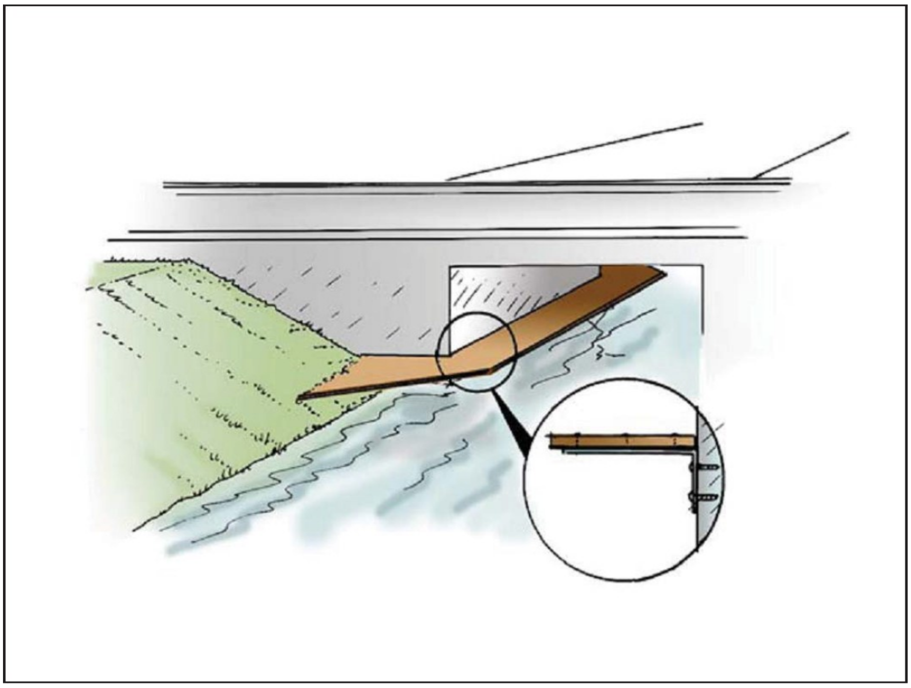


Figure 9. Schematic diagram of a culvert with ledge for wildlife passage (after Clevenger and Huijser, 2011).

Interior walls

4.11 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

4.12 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 10). 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 inside the crossing if small mammals, amphibians and reptiles are also the target groups.

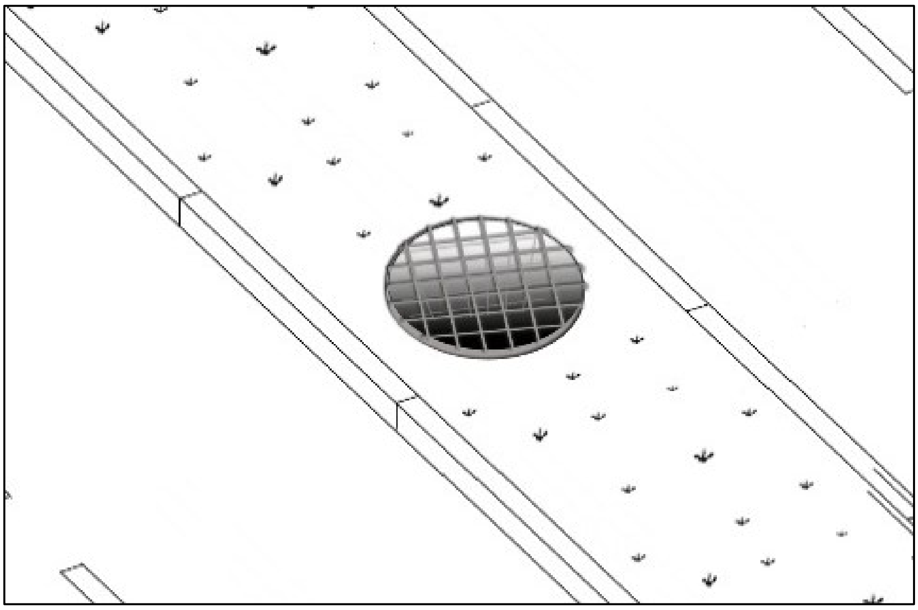


Figure 10. Circular light shaft in the central divider

5. Fencing mechanism

5.1 Fencing mechanism is particularly useful for roads constructed at grade. Barrier fence along the roadways in both directions of the crossing structures helps to keep wildlife off the road while guiding them to the crossing structures (Bond and Jones, 2008). In the project "Improvement to Tung Chung Road between Lung Tseng Tau and Cheung Sha" on Lantau Island, a fencing mechanism was introduced to keep small mammals and amphibians, particularly the Romer's Tree Frogs (*Liuixalus 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 new road.

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. The fencing for large mammals may have no effect in impeding the movement by small mammals, while the fencing mechanisms for amphibians and reptiles would also be different from that for mammals. 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 11).

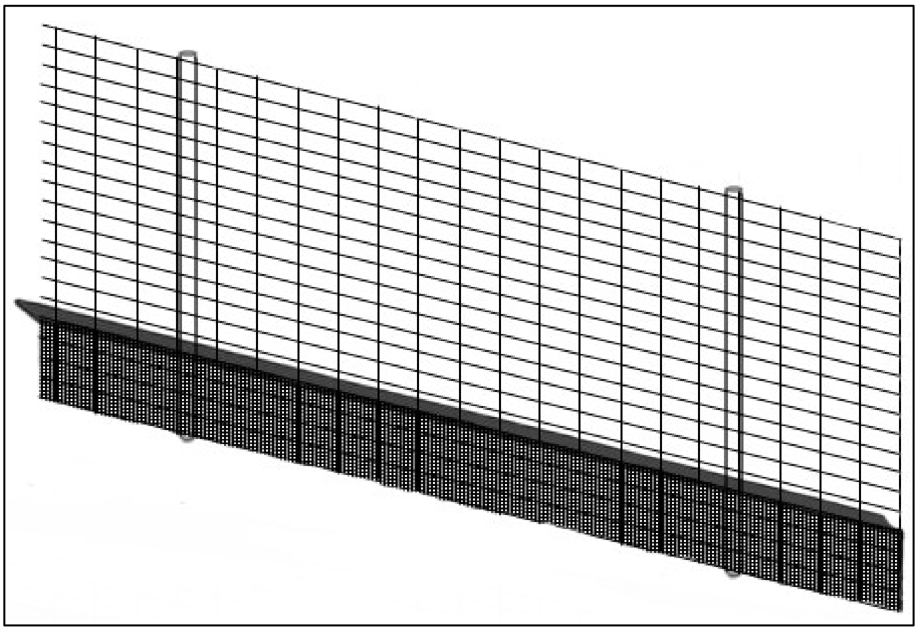


Figure 11. A double fence consisting a high, large-mesh fence and a low, fine-mesh fence. The fine-mesh fence is bent over at the top to stop animals climbing over it.

5.4 The movement of amphibians is usually seasonal and periodic, i.e. occur mainly on breeding seasons. Therefore, temporary barrier or drift fence could be used to direct the movement of the migrating amphibians across the road, or to collection buckets where they would be picked up and transported across the road manually (Figure 12).

Figure 12. Drift fence and collection buckets for amphibians (after Clevenger and Huijser, 2011).

Fence top and bottom

5.4 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 13). 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 14).

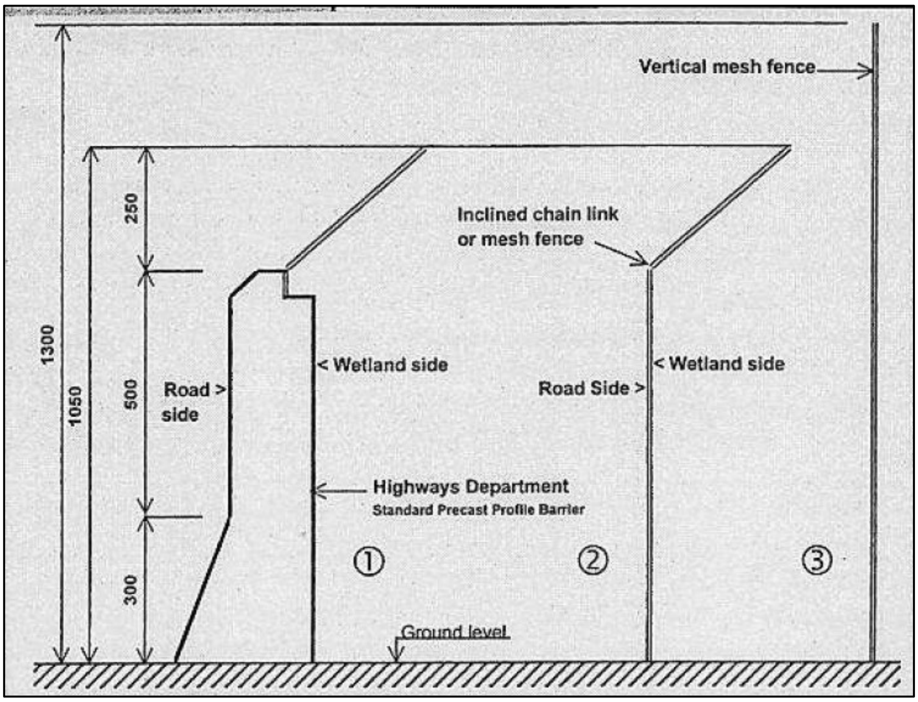


Figure 13. Design of the top and bottom of the fencing constructed for the project Sheung Shui to Lok Ma Chau Spur Line - Operation of the Public Transport Interchange at Lok Ma Chau Terminus and the Station Access Road (after Environmental Permit No. FEP-05/129/2002/F).

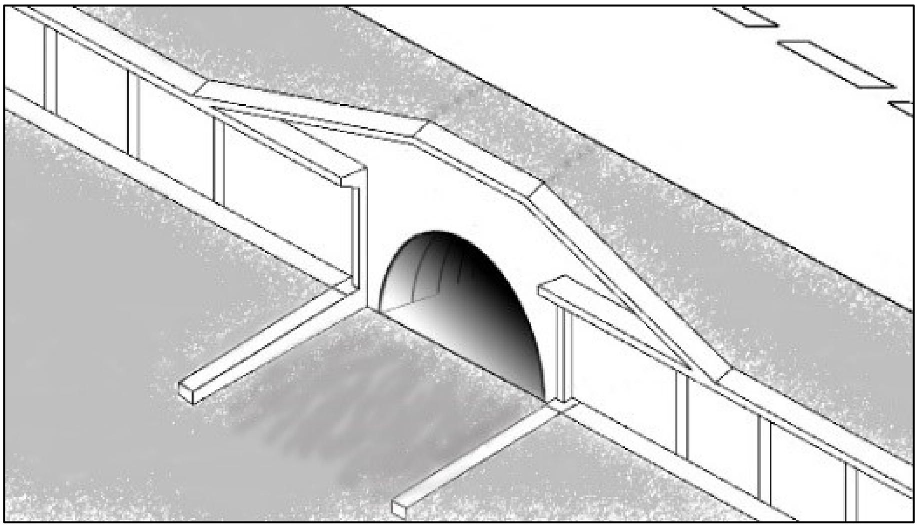


Figure 14. A tunnel underpass with lipped concrete wall for amphibians and reptiles

5.5 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 15).

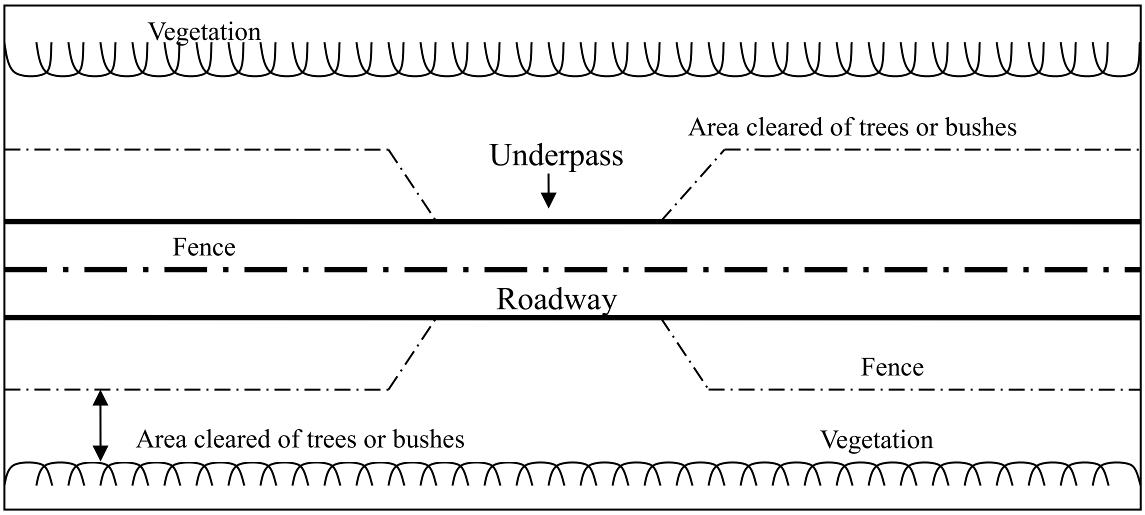


Figure 15. General design of fencing mechanism for a wildlife underpass (modified after USDA Forest Service, 2005).

5.6 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

5.7 While overpasses/underpasses provide connectivity above/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 overpasses/underpasses. Common examples of exits from the fencing include one-way gates or escape ramps at regular intervals (Figure 16). In areas where amphibians are of particular concern, ramps or breaks in kerbs and drains along the roads could prevent entrapment of these animals.

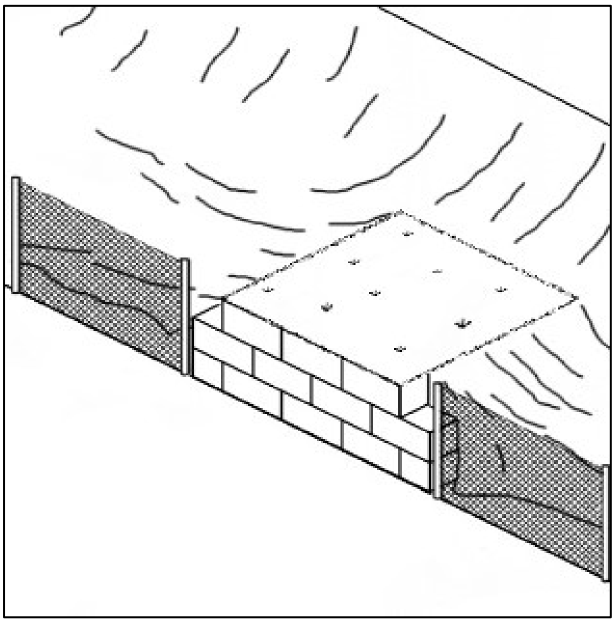


Figure 16. An escape ramp along fencing.

6. Consideration for different wildlife groups

6.1 Design of wildlife crossing should always take into account the ecology and behaviour of the target species. For example, a moist substrate is essential for amphibians and reptiles, while mammals are generally indifferent to the substrate surface. For semi-aquatic species (e.g. Otter), crossing with an appropriate water depth is recommended. Locality of wildlife crossings should also be identified based on factors such as land cover type, elevation, slope, human disturbance, water and food source of target species (Liang et al., 2016).

6.2 The terrestrial wildlife groups which are susceptible to barrier effects of infrastructure include mammals, reptiles and amphibians. These animals can be generally classified into three functional groups, namely large 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)

Animal Group	Large Mammals	Small Mammals	Amphibians / Reptiles
Head-to-body length	≥ 25 cm	< 25 cm	-
Local Examples	Chinese Pangolin (*Manis pentadactyla*) Leopard Cat (*Prionailurus bengalensis*) Red Muntjac (*Muntiacus muntjac*)	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**	√	√
Box culvert	**O**	√	√
Bridge underpass	√	**O**	**O**

7. Maintenance and Monitoring

7.1 Maintenance of wildlife crossings and the associated structures is required to ensure their effectiveness over time. Maintenance includes clearing debris or other impediments to movement through the crossing, replacing shelters such as piles of gravels or vegetative debris, and maintaining adjacent habitat to encourage wildlife movement. For underpasses, the structural stability and sign of erosion surrounding or inside the crossing should also be checked. For overpasses, regular vegetation management is also required to maintain the condition of the crossing.

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 crossings, which is indicated by the signs of wildlife usage. Besides the traditional methods of identifying animal dung and footprints found in wildlife crossings (e.g. by track plates filled with soot or gypsum powder or tracking beds with sand or ink), camera traps can also be used to monitor wildlife uses of the crossings (Figure 17).

Figure 17. Camera trap installed to monitor the wildlife uses of wildlife crossing.

7.4 Camera traps mounted in wildlife crossings make it possible to capture images or even observe the behaviour of the wildlife utilizing the structures. They are proven effective in documenting animal use of larger underpasses (e.g. bridges or box culverts) and overpasses. Mammals have been recorded by camera traps installed inside the wildlife underpass crossing underneath Route 3 and Tung Chung Road (Shek and Wan, 2006; Figures 18).

Figure 18. A Small-toothed Ferret Badger utilizing the wildlife underpass underneath the Tung Chung Road.

7.5 The findings obtained from the monitoring would provide valuable information for planning and designing new wildlife crossings in future projects. For example, microhabitat elements within the crossing may require changes if monitoring indicates that they do not facilitate movement of wildlife; or fencing designs may need to be modified if they are found to be ineffective in impeding the crossing of targeted animals. These adaptive management will allow timely changes to the crossing, which conserve the effectiveness of wildlife crossings to the targeted animals.

8. Enquires

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

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Further Readings

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