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Development of Structurally Improved Erosion Control Dam Models for Ecosystem Connection in Mountain Streams

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Abstract
Non-permeable check dams (erosion control dams) have been constructed to serve specific purposes such as water storage, fire control etc. For example, the gravity check dam serves to block the passage of sediments. Numerous tons of sediments, plant material (e.g. dead leaves) etc. accumulate in these non-permeable check dams, thus rapidly degrading the upstream water. There is need to improve on the permeability of check dams by creating ecological corridors in the non-permeable check dams so as to enable upstream to downstream movement of sediments, animals such as fish, amphibians, control pollution etc. to create ecological harmony in the upstream and downstream environments. This study is therefore very important in that it highlights the challenges associated with the use of non-permeable check dams. It was thus necessary to conduct this study so as to ascertain the importance to improved check dam permeability and as well develop cost effective check dam models. Structural improvement of the existing non-permeable check dams was carried out via demolition, drilling of dam walls to create drainage holes (Φ100 mm pipe in drainage holes replaced with Φ300mm pipes), and this has necessitated the development of improved permeable check dam models with drainage holes that as well serve as ecological corridors. Thus, there is need for improvement of the existing check dams to more ecologically-friendly structures. The required check dam shapes, construction materials and colors depends on the geographical/environmental conditions of the area. In addition, in landslide vulnerable areas with shallow landslides, especially in mountainous valley areas with constructed houses, it`s usually a big challenge to construct large check dams, thus the new model mini-type or membrane type check dams which are less costly, with narrower width and adequate height could best serve in preventing casualties and damages, and enabling harmony with the environment. Constructing these smaller size check dams in areas were landslides are characterized by smaller mass of material movement is thus best suited in such areas as it is cost effective.
Keywords: Check dams, dead leaves, ecological corridors, landslide, permeability, structural improvement

1. Introduction

Massive landslide disasters occur in mountainous areas caused by extreme weather events like typhoons and torrential rains, with the disaster pattern varying from one region to the other. In 2006, typhoon EWINIAR and torrential rains caused severe damages in 7 groupings including Inje, 5 provinces including Gangwon and Pyeongchang, as well as 18 cities and counties across South Korea, and this was classified a special disaster in the area (Seung et al., 2008; Ma et al., 2016). Large-scale landslides with massive debris flows causing huge casualties and property damage occurred in 2011 in Mt. Woomyun of Seoul and 2012 in Hamyang County, Sancheong, and Geochang in Gyeongsangnamdo Province (Ma et al., 2016). Flood and landslide disasters in mountainous areas in Korea caused by typhoons and torrential rains have emerged due to critical land management issues.

It is necessary to construct check dams in areas remarkable for landslides and soil runoff to enhance effective watershed management (Jeong and Ma, 2007; Jiang *et al*., 1994; Xu. *et al.,* 2004). However, the damming of rivers or streams provides a dominant human impact on river or stream environments, with subsequent ecological impacts downstream which can be extensive (Graf, 1999; Jeffrey et al. 2008; Nilsson et al. 2005; Palmer, 1991;). Damming could result in fragmentation of river corridors, interrupting downstream passage of biota which would therefore result in downstream ecological impacts (Jansson et al., 2000; Ward and Stanford 1995;) as well as cause pollution upstream, with the eventual problem of sedimentation (Pham et al., 2001) which might affect the lifespan of the dam (Poff and Hart, 2002).

Check dams have been constructed in mountainous areas to aid in effectively preventing/reducing possible damages from landslides such as debris flows in the watersheds. Appropriately located check dams can reduce harm from driftwood and debris generated during heavy rains upstream.

Erosion control dams installed in mountain valley areas, with the dam designed taking into consideration the importance of biodiversity conservation have very high ecosystem connectivity. In mountain forest areas were wetland biodiversity conservation is carried out, erosion control dams in such areas take into consideration the use of environmentally friendly materials, hydraulic facility installation, scenery of landscape, the introduction of local vegetation, aquatic animals and wildlife ecological corridors, thus assuring its capacity as natural habitat for plants (Kim, 2008).

Today, there has been increasing interest in ecological harmony with the natural environment, ecosystem conservation, spatiality of vegetation etc. thus depending on the needs and scope, consideration is been given to ecological pathways or corridors in permeability-dams (Ma et al., 2016). Nature friendly dams of different forms are been constructed.

Erosion control dams located in mountainous stream areas may cause damage to biodiversity by interfering with the connectivity between habitats or inhibiting movement. Also, sediments and dead plant material usually accumulate in erosion control dam, causing significant impact on aquatic ecosystems (Ma and Jeong, 2007). The terrain and the ecological characteristics of the area have to be taken into consideration for the facilities of erosion control dams (Kim, 2009).

Small check dams are cost effective and more required in shallow landslide areas. Such small check dams are intended to control the undercutting of valley side slopes and prevent landslides, to reduce channel gradient and thereby induce deposition of debris flows, and to trap sediment (Abedini et al., 2012).

The current study therefore seeks to improve ecological permeability of check dams by developing structurally improved check dam models, as well as conduct structural improvement of the non-permeable check dams to enhance appropriate protection and management of biodiversity in mountain areas. Also cost effective small size structurally improved check dam models are developed.

2. Material and methods

2.1 Site description

South Korea is generally mountainous with over 70% of the total area made of mountains and uplands. These areas consist of numerous mountain streams most of which are shallow and intermittently flowing (Joo et al., 1997), as well as vast forest area. This study was carried out in Gyeongsangnam-do Province characterized with numerous mountain streams. Many different dams have been constructed in these areas many of which are huge, expensive and non-permeable. The mountains are a major habitat for aquatic organisms. Of a total of 212 freshwater fish species recorded throughout the Korean peninsula, about 50 species (23.6%) are believed to be endemic, many occurring in the mountainous regions (Kim and Park, 2002).

2.2 Dam permeability

In order to recommend structural improvements on erosion control dams considering the ecosystems in South Korea, the structure of the dams in the study area with their existing facilities were examined with respect to openness to enhance downstream movement of sediments and animals (Ma et al., 2016). Analysis of the typology and ecological problems with respect to permeability of constructed concrete check dams were done, with proposals made for improved dam design to enhance/or improve ecological permeability of the check dams. The sizes of the drainage pipes were measured and larger pipes installed. Drilling of drainage holes using drillers was done on dam concrete walls as well as demolition of part of the dam using demolition machinery to improve dam permeability.

2.3 Pollution evaluation

Observation and evaluation was carried out for accumulated matter (plant, animal and sediments) around the dam, blocked from flowing downstream by the check dam, and the dam drainage areas evaluated, thus giving the basis for recommended permeability improvements of check dams. The downstream conditions were also observed and evaluated.

3. Results and Discussion

3.1 Material deposition and pollution around the non-permeable dams

Large sediments and dead leaves accumulated in the upstream section of the check dams. The sediments occupied most of the stream bottom while dead leaves occupied most of the water surface. Some dead organisms like frogs were also recorded in the upstream area. Decomposition of the dead leaves and animals generated intense odor perceived in the area as well as very high pollution of the upstream dam environment. The downstream section of the dam had minimal pollution with smaller sediments and few leaves observed flowing in the water. The downstream water was relatively pure, thus the existence of the non-permeable check dam degraded the upstream environment.

3.2 Structural improvement of erosion control dam with consideration to the ecosystem
3.2.1 Improvement in the structure of the non-permeable check dams
3.2.1.1 Major improvement of concrete check dam structure through drilling
Structural improvements of concrete check dams were carried out for 2 check dams, located in Sacheon, Gyeongsangnam-do. Figure 1 shows a non-permeable check dam with the top left and right side view and front view of check dam. At a height from the base of 1.5m is inserted a Φ100 mm pipe for water passage (Fig. 1a), while as seen in Figure 1b, a structural design and improvement has been carried out at a second level of the dam.

a) Front and side view of non-permeable dam b) Front and side view of dam with structural improvement
Figure 1. Example of on-going structural improvements of non-permeability Erosion Control Dam via drilling of four drainage holes.

The non-permeable check dams with Φ100 mm pipe at a height from the base of 1.5m does not properly enhance movement of materials downstream as the passage is narrow. More sediments and dead leaves accumulated in the upstream section of the dam. Leaves and other waste also accumulated in the pipe further blocking the passage of materials. After increasing the pipe size by using Φ300mm pipes inserted on 4 drilled holes on the check dam wall at a reduced height from the base (Fig. 1b), downstream movement of materials, and passage of animals was improved and enhanced as the pipes served as ecological corridors. Upstream water pollution was thus minimized with easy water flow enhanced.
3.2.1.2 Structural improvement of check dam boulders by replacing with water pipe
The check dams were constructed with stone boulders, with narrow drainage pipe of Φ100 mm inserted close to the base, thus with the accumulation of fallen leaves and rocks, passage via the pipe was difficult.

Figure 2. A check dam with structural improvement to enhance drainage

After installing Φ300mm drainage pipes at the lower part of the check dam base (Fig. 2), water passage was enhanced via the pipes during summer rains as well as downstream movement of materials, and also in the dry season were the pipe continuously served as ecological corridors.

As seen in Figure 3, attached to the Φ300mm water pipe is a facility with an adjustment valve. This enables adjustment to enhance a water storage function when necessary, and the passage of water via the dam to prevent accumulation/clogging in the inlet pipe with L, T type connection. Figure 4 shows an improved check dam with Φ300mm drain valve that can be regularly adjusted. When the upstream is full to capacity, water drains downstream via the overflow drain halfway of the dam, and in the dry season, the drainage valve serves as ecological corridor to regulate movement of aquatic organisms.

Figure 3. Improved drainage practices (water pipe Φ100mm ⇒ replaced by Φ300mm at the base area)

Figure 4. Structurally Improved check dam (Φ300mm drainage valve and half way fresh water overflow).

3.2.1.3 Structural improvement through demolition of some boulders in the erosion control dam

Structural improvement was done on a check dam located in Yangsan city, Gyeongsangnam-do Province of South Korea (Simyeong Temple), were numerous hikers complained that the check dam located at the upper valley was highly polluted with fallen leaves following heavy rains that cause water accumulation in the dam. The check dam is located at Yangsan at mountain road 71-1 (Simyeongsa) constructed from March 26 to June 27, 2009 by Gyeongsangnam-do Forest research project costing about 115,000 USD, with the check dam having the following dimensions (length 35m, height 6.2m, average height 4.6m). Follow-up and maintenance was not done on the check dam after construction, leading to the accumulation of sediments up to several tens of tons, including leaves and tree branches with dead matter that decomposed and polluted the valley area. Therefore, the check dam became environmentally-unfriendly to nature as problems of water pollution, degraded environmental beauty and ecological permeability was inhibited.

Figure 5 shows the water highly polluted as a result of the non-permeability of the check dam while the right picture shows dark leaves, with bad odor perceived in the area. When the reservoir water within the check dam area became stagnant for a long time, it eventually deteriorated and the polluted water generated odor perceived by local residents and visitors to the mountain area. This thus conforms to the fact that, the damming of rivers or streams provides a dominant human impact on river or stream environments, with subsequent ecological impacts in the stream which can be extensive (Jeffrey et al., 2008; Nilsson et al., 2005; Palmer, 1991).

Figure 6 shows on-going structural improvements being carried out at the check dam via demolition of target boulders. Improving the dam structure eases downstream water flow thus accumulated sediments upstream are eventually cleaned-up (Figure 7). Thus when non-permeable dams are improved structurally (Figure 7), water pollution is minimized as downstream movement of sediments, animals and plant materials from upstream is enhanced, with the creation of ecological corridors.

Figure 5. Water pollution caused by litter accumulation in a non-permeable check dam

Figure 6. On-going structural improvement of check dam via demolition to create passage way

Figure 7. Structurally improved check dam showing visible passage ways from upstream to downstream. Water pollution is mitigated as water easily flows and carries materials along.

3.3 Proposed new check dam models for landslide management and drainage improvement

3.3.1 Mini type check dam model

Generally, bigger and much higher check dams are constructed to manage debris flows in mountain valley areas, but considering small private houses or shallow landslide vulnerable areas, mini-type check dams with narrow widths and heights are more adapted, to serve as relatively improved check dam models in such areas. Figure 8 shows the 12 different types of mini-type check dams with varied permeability, ecological barrier height and spillway area.

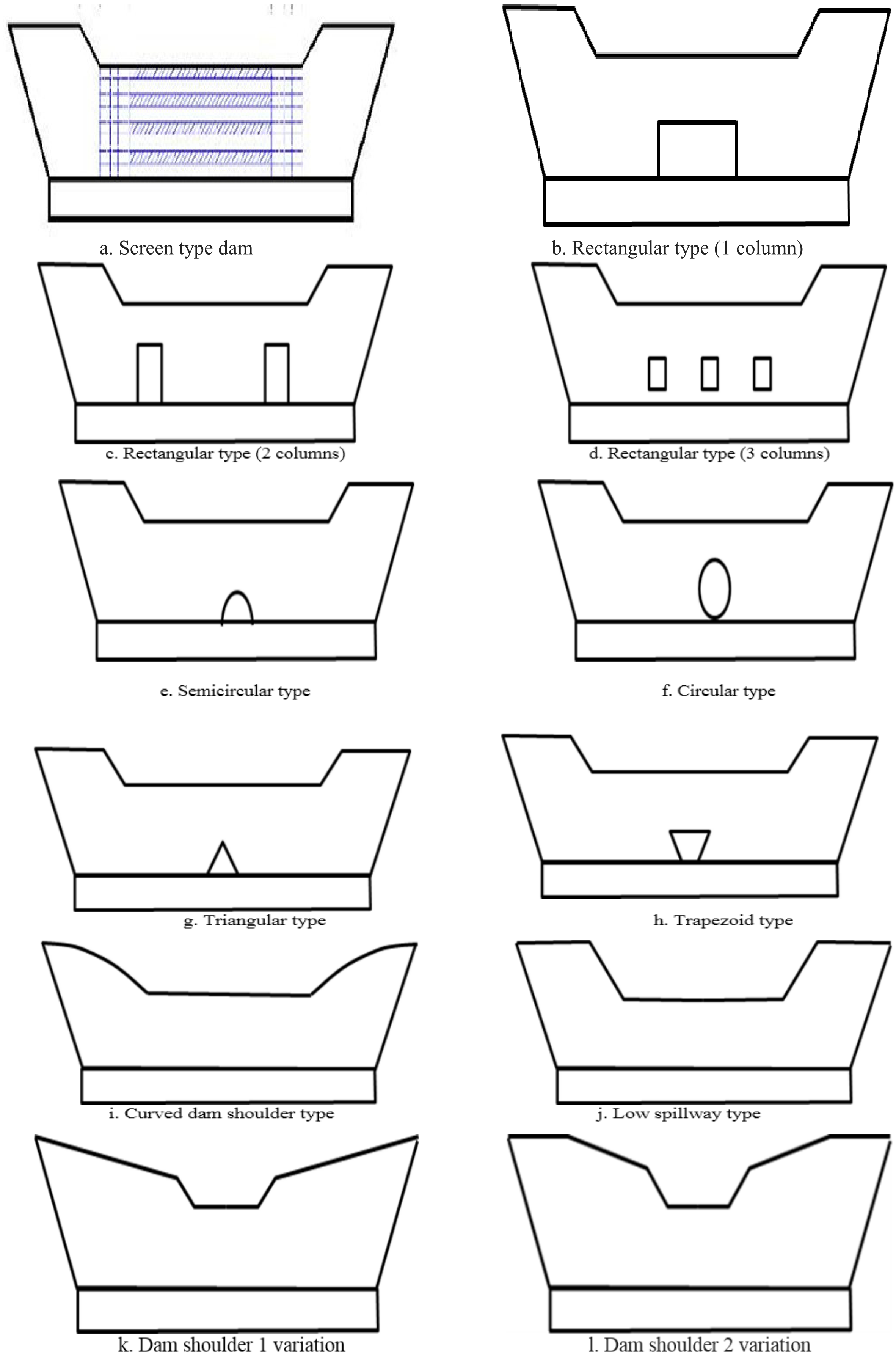
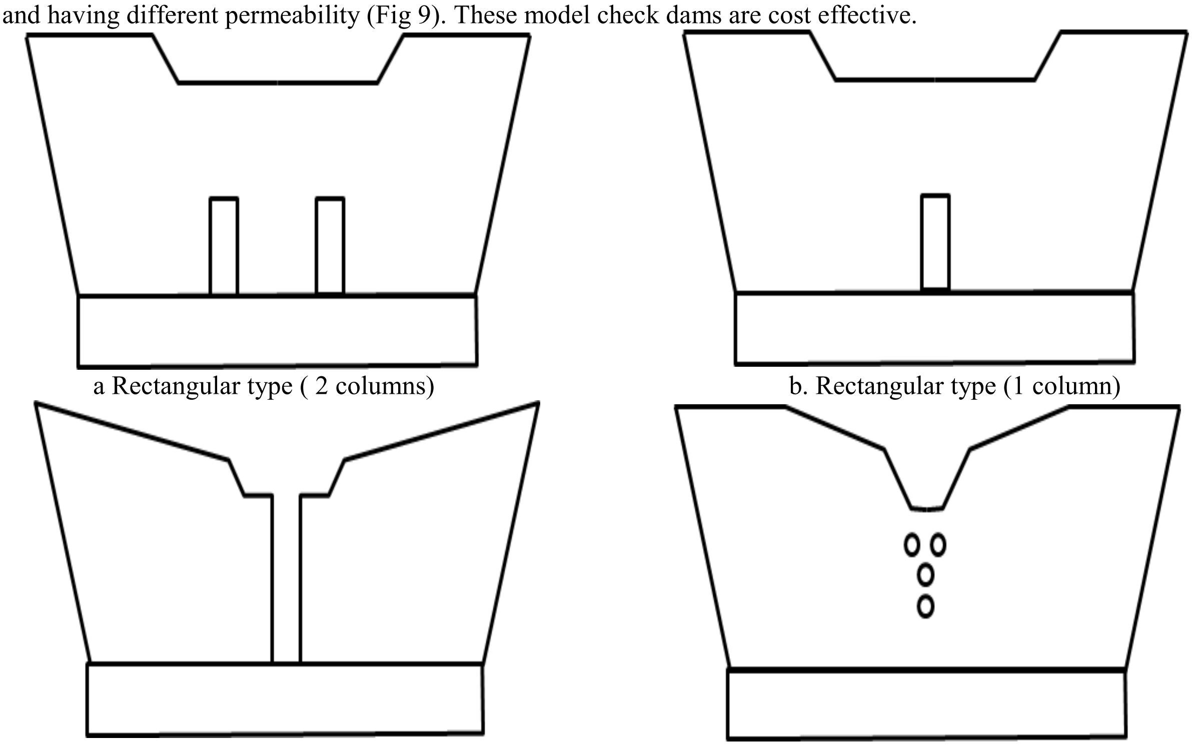


Figure 8. The new mini-type check dam models with different designs.

These mini-type check dams are less expensive, and should be constructed very firm enough for sustainability. When detailed studies are conducted in the area, the position and design of the mini-type check dam which is best suited for the area is determined, considering the environmental conditions and ecological diversity of the area.

3.3.2 Membrane type check dam models

In vulnerable landslide areas with smaller material mass especially around private houses close to small cities, four different check dam types are proposed with the heights and forms taking into consideration the location and having different permeability (Fig 9). These model check dams are cost effective.



a Rectangular type (2 columns) b. Rectangular type (1 column)

c. Dam shoulder type 1 d. Dam shoulder type 2 (Drainage type)

Figure 9. Check dam models having different permeability suited for shallow landslides

3.4 Drainage hole improvement model

Structural improvement to enhance drainage in erosion control dams is principally for non-permeable check dams with low ecological permeability. Such structural improvements entail demolishing concrete walls to create spillways, and such demolishing and expansion of the spillway is usually an expensive process which in some cases is impossible to be done. Thus the use of methods of structural improvement of the check dam that will enhance drainage via inserting holes without necessarily needing the massive demolition of the check dam is seen as a better and preferable alternative.

When a drainage hole is created in a check dam, it increases connectivity and sediment flow between upstream and downstream as well as enhances movement/passage of animals and plants, thus enhancing ecological permeability.

The higher the permeability of a check dam to enhance upstream to downstream passage of animals and plants, the more the role of a smooth moving stream or river to enhance sediment movement from upstream to downstream. Also, instead of hindering upstream to downstream movement of plants and animal matter in mountain streams, a permeable check dam will create ecological corridors that effectively promote maintenance of biodiversity in the watershed. There is generally a balance of sediment inflow and outflow in natural river reaches (Mandana et al., 2012), but dam construction alter this balance (Petts and Gurnell, 2005), especially non-permeable gravity dams which in addition to its contribution in reducing the velocity of stream or river flow, it accumulates sediments in it. Reduction in the volume of downstream flow and timing of flow are thus major ecological alterations (Williams and Wolman, 1984; Magilligan et al., 2003).

Model check dams to enhance ecological permeability by improving non-permeable check dams with drainage holes are shown in Figure 10. Figure 10 shows improvement of non-permeable check dams while maintaining its initial functions, but as well providing additional functions of enhancing ecological permeability as with rectangular, triangular, semicircular, circular, and trapezoidal check dams.

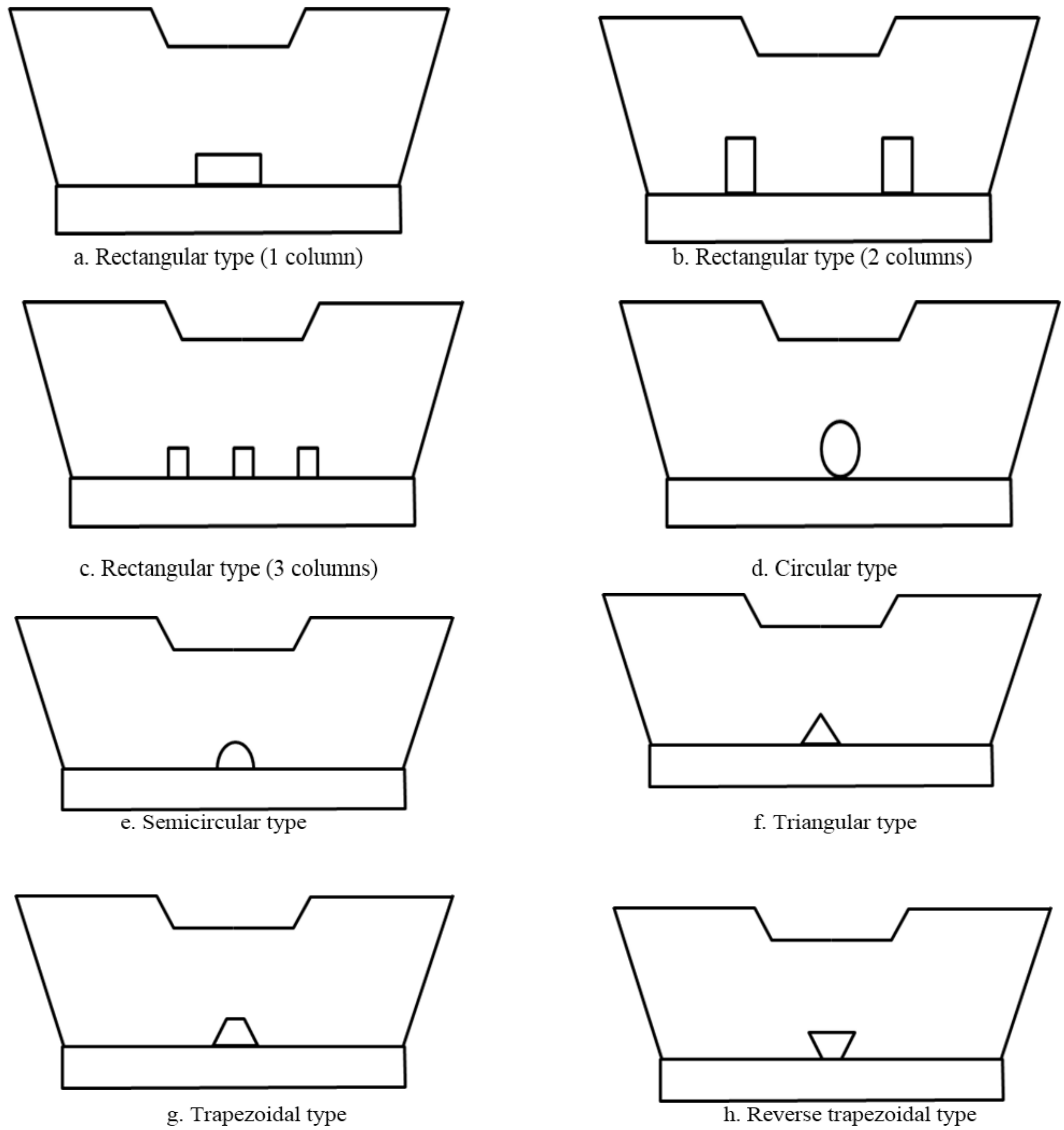


Figure 10. Drainage hole insertion model check dams. The drainage holes enhance upstream to downstream connectivity, thus mitigating pollution and water degradation as well as ease movement of animals. The biodiversity and water volume will guide the selection of the dam type needed for the area.

4. Conclusions

The results of this study thus summarizes the new model and structural improvements required for non-permeable check dams constructed in valley areas, that would improve ecological connectivity and ensure appropriate protection and management of biodiversity around watersheds. In order to improve the structure of non-permeable check dams, over 8 new check dam models are proposed that would entail putting in place drainage holes in the check dams such as for rectangular, circular, triangular and trapezoidal type check dams. Structural improvement of concrete non-permeable check dams would require improving permeability of the dam with a replacement of the 100mm diameter pipe size and using the larger 300mm pipe sizes so as to increase the ecological permeability of the dam. Structural improvement of the non-permeable check dam via some demolition to create drainage ways, helps to improve water quality and prevent deterioration of litter, as passage via the ecological corridor created is enhance, with upstream to downstream flow improved. To enhance structural improvement of non-permeable check dams, 12 forms of mini-type check dams are developed which include; screen type, rectangular type, semicircular type, circular type, triangular type, Trapezoid type, curved dam shoulder type, low spillway type, dam shoulder 1 variation, dam shoulder 2 variation etc. The construction of large check dams will vary according to the region with its characteristic challenges, but around the surrounding of private houses, in order to prevent damage to property and ensure harmony of life with the environment, there is the need to develop and construct mini-type check dams (relatively narrow with lower heights). These dams are cost effective. Structurally improved check dams will curb water pollution and degradation, as water easily flows carrying along polluting materials and blocking larger materials like tree branches which would be removed during regular monitoring of the dams. Future research is required to record and measure the amount of plants, animals and sediments within the different check dams.

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