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Ecological engineering methods for soil and water conservation in Taiwan

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ABSTRACT

This paper describes the development of Taiwan's localized ecological engineering methods to make the mitigation works more effective. To strengthen the soil and water conservation and protection of the ecological environment, comprehensive mitigation planning is necessary with considerations that include balancing the safety, ecology, and landscape, and treating the whole watershed as a unit. To demonstrate the achievement of the promotion of the ecological engineering methods in Taiwan, this paper illustrates two complete mitigation examples for a debris flow torrent and a stream. Most of the mitigation works have survived and are still stable (with some minor damages) after the two strong typhoons of 2004. We show that the developed ecological engineering methods are very suitable in mitigation and worthwhile for further promotion for Taiwan's ecological environment.

1. Introduction

One of the important measures in soil and water conservation in Taiwan is the ecological engineering method. It can be an index of protection and restoration for ecology. In 2001, the Soil and Water Conservation Bureau (SWCB) in Taiwan began to promote the innovative ecological engineering methods. Disaster prevention, ecological conservation and recreation have been interwoven by the adoption of ecological engineering. Ecological engineering methods are suitable for regions with medium size flooding potentials. They can be used to regulate stream course, guide dangerous current to floodplain or detention ponds for safety, and reduce some sweeping forces of rapid currents. The method should not be considered a complete flood control measure. With debris flow torrents or very rapid stream flow, conventional engineering may be inevitable to maintain the overall stability of areas vulnerable to landslides or debris flow, and to control any debris overflow. If the much stronger conventional structures such as slit dams and check dams are indicated, environment friendly considerations should be made as much as possible while building them. When the unstable hazard zone is properly protected by conventional works, the risk of washout/failure of the much more flexible ecological engineering methods can also be reduced; and the functions of ecological engineering methods can develop faster and help the environment and habitats to restore gradually. This is like an "ecological therapy" to nurse the once damaged environment.

For ecological engineering, two major approaches were adopted: develop new techniques and apply newly developed ecological engineering methods. The tasks for promoting ecological engineering methods include the develop-

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ment of reference drawings for ecological engineering methods, ecological investigations, habitat improvement, establishment of ecological indexes, development of vegetation methods in landslide areas, and holding a series of conferences for ecological engineering methods. The methods are created to suit the domestic biological and environmental conditions. The merits of ecological engineering methods lie in the emphasis of comprehensive considerations in all aspects for soil and water conservation tasks. This paper shows that ecological engineering can be properly applied to mitigation of watershed disasters, protection and restoration of ecology. In addition, recreation infrastructures, rural community, and agricultural economic can be simultaneously developed.

2. Ecological engineering methods and habitats

2.1. *The functions of ecological engineering methods*

(1) Improving the revival ability of ecosystem (for large scale hazards such as landslide and debris flow): Ecological engineering methods can be suitable for mitigation of large scale natural hazards if the works are designed to provide the ability of revivification for the natural environment, ecosystem, and the corresponding peripheral characteristics.
(2) Improving the protective ability of ecosystem (for medium scale hazards such as scouring of streambank and streambed): The methods should consider porous materials that will form many voids to provide shelter and protection for both aquatic and terrestrial animals. The mitigation should consider overall characteristics of watersheds and maintain the connections to the original natural stream environment, and avoid changing the current ecosystem or a single purpose construction.
(3) Improving the recoverability of ecosystem (for small-scale hazards such as surface erosion): Original local materials such as local stones, local woods, and local plants should be adopted for mitigation and the methods should have the ability to improve the recoverability of ecosystem.
(4) Improving the functions of streams (for the streams with mitigation done): Design of stream mitigation and rehabilitation should consider incorporating the local environment, potential purpose of recreation and compatibility of future residential construction. The functions of stream mitigations can be improved with the incorporation of the ecological engineering methods such as building recreational area, scenic streambank, and ecological buffer zone.

2.2. *The functions of the ecological corridor*

The objective of creating an ecological corridor is to retain or rebuild the major routes for local fauna's needs for survival, breeding, food, and migration. The role of the ecological corridor includes conduit, habitat, filter, barrier, source, and sink (Noss, 1991). Some examples of ecological corridors in Taiwan are discussed below.

Fig. 1 – After establishing the fish passage, more fish species are found and their activities obviously increase.

(1) Improvement of longitudinal ecological corridor
In 2003, at Liu-chung Creek in Tainan County, a longitudinal ecological corridor (a fish passage) as well as a sediment control check dam were constructed upstream. A census of fish species was conducted at pre-construction, during-construction, and post-construction (SWCB, 2003a). The pre-construction investigation shows fewer fishes existed in the upstream due to 1.3 m gap in the creek, which prevented fish from migrating upstream. After the corridor was implemented with a fish passage (Fig. 1), the number of fish in the upstream measurably increased. In addition, fish appeared more active. This may be because the swimming space has expanded and the chance of inbreeding has been minimized.
(2) Construction of longitudinal corridor
Hou-fan-zi-keng Creek is located in Taipei County in northern Taiwan and it is abundant with various species. In July 2001, Typhoon Nari caused the collapse and erosion of the banks. The creek changed its course and caused severe sedimentation. The habitats in the creek were destroyed and the survival of many aquatic animals was threatened (Fig. 2). In order to revitalize the ecology, non-cement based ecological engineering methods were used, including wood-log pile shoring for bank protection and arc-shape stone streambed sill for the lon-

Fig. 2 – The pouring rain of Typhoon Nari in July of 2001 eroded the river course at the downstream of the Shen-nong Bridge.

Fig. 3 – After the flood during Typhoon Mindulle in 2004, the downstream of Shen-nong Bridge shows no damage and the river course becomes naturally meandering.

gitudinal corridor. It is also hoped to rebuild the natural scenery of the stream (Fig. 3). To provide a suitable habitat, the meandering of the creek was designed to create various aquatic environments such as pool, shoal, riffle, backwater, and slack. Based on the comparison of pre- and post-construction investigations (SWCB, 2003b), fish and shrimp have returned to the creek and increased in large numbers. The obstacle-free arc-shape streambed sills and the slacks help fish migrating between upstream and downstream.

(3) Improvement of lateral corridor using gentle slopes
In the debris flow mitigation at Chung-ho Village in Taipei County, gentle slopes of streambank protection were designed to fit the topographical flat area. The gentle slopes serve as an interaction base for both aquatic and terrestrial animals ensuring the continuity of the lateral corridor (Fig. 4).

(4) Example of pitfalls due to lacking gentle slope
The bank mitigation design for debris flow of Da-tsu-keng Creek in Taipei County was 1:1 sloping with slit dams. There was no designated gentle slope. When a deer entered the creek for food, it fell into the channel which is 3 m lower than the bank and could not climb back up by itself. Out of fear, the deer cried out and dashed down in the creek. With great effort, people rescued it. This should teach us a lesson about the importance of having a gentle slope zone and ecological corridor.

Fig. 4 – Gentle slopes of streambank protection of Chung-ho Village in Taipei County.

2.3. *Some drawbacks of conventional engineering*

Natural streambanks allow water seepage. Organic matter and minerals in the ground will be carried by groundwater entering a stream. Natural porous materials enable the exchange of water, which maintains water quality. Using concrete in preventing flood and erosion is considered safer than natural streambanks. However, it will break the continuity of groundwater. Also, some channelized streams were built with smooth vertical concrete revetments. Such design will cause problems such as difficulty in planting, fish migration, and amphibious reptile travel.

Tall slit dams will cut off longitudinal ecological corridors. For a perennial stream, a slit dam will block fish migration. A fish passage should be considered. Check dams with drops higher than 1 m can hinder fish migration also. For flow regulation works, a concrete paved streambed will make pool, shoal, and riffle disappear; and water quality will be easily degraded.

3. Planning and design of stream mitigation using the ecological engineering methods

3.1. *Fundamental concepts*

(1) Consider balance in safety, ecology and landscape
Consider the priority and balancing of safety, ecology and landscape according to the regional characteristics. Safety shall be the first considered for the hillslopes near urban areas. In contrast, ecology should be the major factor for mountain hillslopes with various ecological systems. For other areas safety, ecology and landscape should evenly considered.

(2) Develop suitable mitigation according to local environment
Create integrated design to be compatible with local environments such as regional ecological resources, natural hazards, environmental characteristics, landscape scenery, historic monuments, and resident opinion.

(3) Perform integrated planning and design for watersheds
Plan hazard mitigation and rehabilitation by taking watersheds as a whole unit including, building natural ecological district, environmental protection area, improving habitats, and recreation areas, etc.

(4) Create aqueous environments
Construct facilities for aqueous ecological environments such as pool, shoal, riffle, backwater, slack, flow deflectors, fish passage, and artificial wetland. Building boulder revetment and rearranging existing rocks in streambed is an excellent method to control the flow speed and to create the above aqueous environments.

(5) Create the terrestrial environment
Construct facilities for terrestrial ecological environments such as vegetation, garden, and terrace.

3.2. *The principles of integrated design for streams*

(1) Build a natural ecological environment
Provide near nature works which help pool, shoal, rapids, riffle, slack, backwater, and flood terrain to develop naturally.
(2) Design flood detention ponds according to landforms
In mitigation of streams we can use open areas, such as flood terrain, playground, wetland, agricultural pond, terraces, as flood detention ponds.
(3) Comply with the original course of streams
It is important to comply with the original course of a stream for streambank mitigation and avoid equal-width or parallel design for channel.
(4) Avoid interfering with habitats
To better preserve habitats, necessary construction should be planned away from ecologically sensitive areas that might be affected.
(5) Design gentle slopes for streambanks
In order to provide the ecological corridor for interchanges between aquatic and terrestrial animals a gentle slope of streambanks less than 1V:1.5H is suggested.
(6) Put stones in stream courses and streambanks to generate porosity and voids
The voids between stones create shelters and habitats for animals. For aquatic animals to find shelter, forage, rest, sleep, and breed, the habitats constructed by concrete structure can be improved by adding surface stones.
(7) Obey the following five principles to efficiently reduce the construction impacts on environments
   a. Use porous materials on structure faces to create roughness and voids to enhance habitats.
   b. Lower height of dams and minimize size of structures.
   c. Make slopes of streambanks gentle to create ecological corridors.
   d. Use natural materials in construction for diversity.
   e. Make interfaces between structures and make permeable ground for water circulation.

4. Selected examples of the ecological engineering methods of Taiwan

Selected examples of the ecological engineering methods of Taiwan are introduced as following (SWCB, 2002a).

(1) Stone revetment
The main purpose of stone revetment is to protect the toe of streambank and avoid erosion (Figs. 5 and 6). In particular it can prevent piping caused by seepage. Well-constructed stone-paved revetment can be considered a retaining wall that withstands active earth pressure of streambank. Stones and the finished surfaces have a natural appearance. The spaces and voids between the stones are advantageous to habitats and better vegetation than concrete revetment. The best stones are those washed down the stream in the past or by debris flows, thus saving money and time from transferring stones from somewhere else. Another benefit of using stones from a streambed elevated by debris flow is that the flow channel can be cleaned and the cross-sectional area increased.
(2) Stone revetment with concrete lining
When safety is more of a concern due to rapid current erosion, and it is deemed beneficial to protect the habitats, an inner concrete lining is used behind the surface stones in addition to the above stone revetment. A concrete lining provides a stronger resistance to flooding. Although the ecological function may be somewhat reduced due to the concrete lining, the backfill with gravel behind the concrete lining can drain off water into the streambank. The surfaces of stone revetment still have natural appearance and increase the roughness of streambank. This stronger method is often necessary for many revetments in Taiwan due to the extreme rainfalls and flooding during summer.
(3) Streambank protection using wood-log piles
The method can be rapidly constructed at low cost and easily adapts to the sinuous geography of streams (Fig. 7). It is suitable for slow current streams or section of gentle slopes. The completed revetment is low, and it is easy to complete reforestation and beautification. The wood piles rot naturally and are decomposed by microorganisms, thus becoming merged to the environment without sacrificing their functions. The method cannot be applied to high erosion potential or rapid current section.
(4) Wood stakes and coir-log revetment
The method is applied to current velocity less than 3 m/s, and where urgent, temporary, and quick treatments are required. The method adopts coir-log for backfill materi-

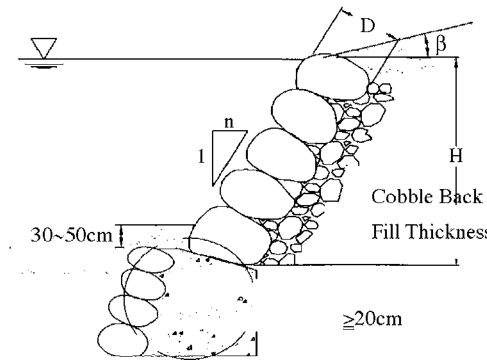

Fig. 5 – A stone revetment (SWCB, 2002a).

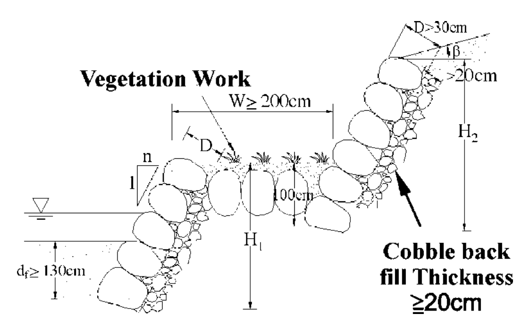

Fig. 6 – A stone revetment with a bench (SWCB, 2002a).

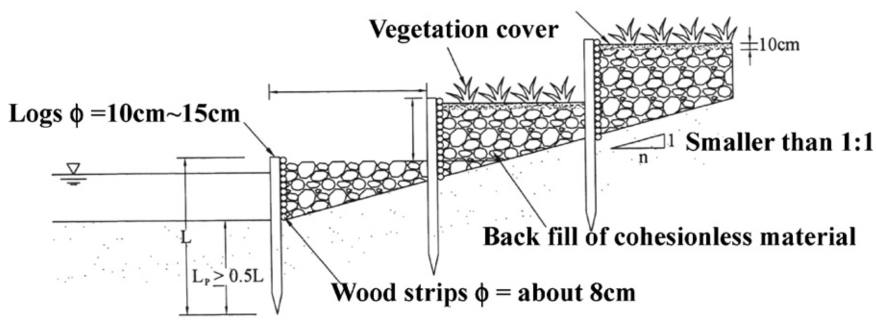

Fig. 7 – Streambank protection using wood-log piles (SWCB, 2002a).

als. The finished revetment has the characteristics of lower height and permeability. The coir-log rolls are made from plant fibers and will decompose eventually (Fig. 8). Similar to wood-log piles, wood stakes and coir-log revetment would rot and become part of the environment.

(5) Boxed gabion revetment
The method is applied to high erosion potential and fast flow velocity sections. The cobbles and gravels confined in gabions provide better resistance than stone revetment for flooding. The permeability is high to easily drain off groundwater and rainfalls. In addition, when the deformation of revetment is not uniform and excessive, the flexibility of the boxed gabions can provide good compatibility for large deformation (Fig. 9). The porosity of the gabions makes it possible for frogs, snails, and other creatures to survive next to streams.

(6) Arc-shape stone streambed sill
In perennial streams, the method can be adopted to prevent the stream from eroding vertically and horizontally, to stabilize the streambed, and to reduce velocity of flow. By applying the arching effect, the method transfers the pressure of running water to the streambank. There is only compression pressure between the stones and no tension. The connected and chained construction is more stable than a single stone. By the stone streambed sills, the stream water will descend to create a diversified water environment such as pool, shoal, and slack, etc. It will increase in dissolved oxygen thus benefitting aquatic animals (Fig. 10).

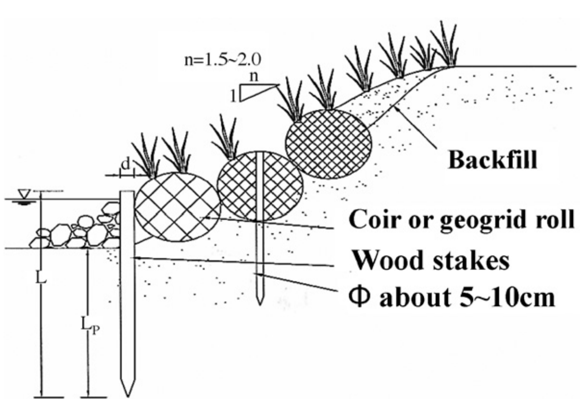

Fig. 8 – Wood stakes and coir-log revetment (SWCB, 2002a).

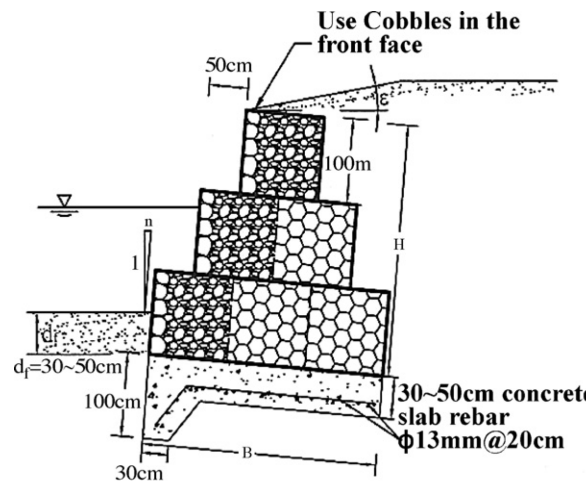

Fig. 9 – Boxed gabions as revetment (SWCB, 2002a).

(7) Slant streambed sill (Fig. 11)
The method can reduce the velocity of flow, stabilize the flow, prevent streambed from scouring, and let the flow course remain stable. It adopts concrete and stone mattress in rapid flow section to reduce velocity and regulate the gradient of stream. It also forms a natural looking stone surface landscape.

(8) Landslide source control with staking and wattling method (Fig. 12)
The landslide source control with staking and wattling is to cutoff/drain runoffs and fill cracks on the top of landslide area. It can reduce a great amount of rainfall entering the landslide prone area thus increasing stability. Staking and wattling is applied on slope face. Drainage systems and vegetation are used to reduce sheet/gully erosion and to increase re-vegetation rate. At the slope toe, stability work and streambank protection can secure an effective mitigation (SWCB, 2002b). Endemic plant species should be planted first with alien plant species carefully selected or avoided. The SWCB usually employed rural village residents or even landslide victims to participate in this method for landslide area. The philosophy behind this approach is that the victims can find new courage for life, and for villagers to treasure their own lands and live in harmony with nature.

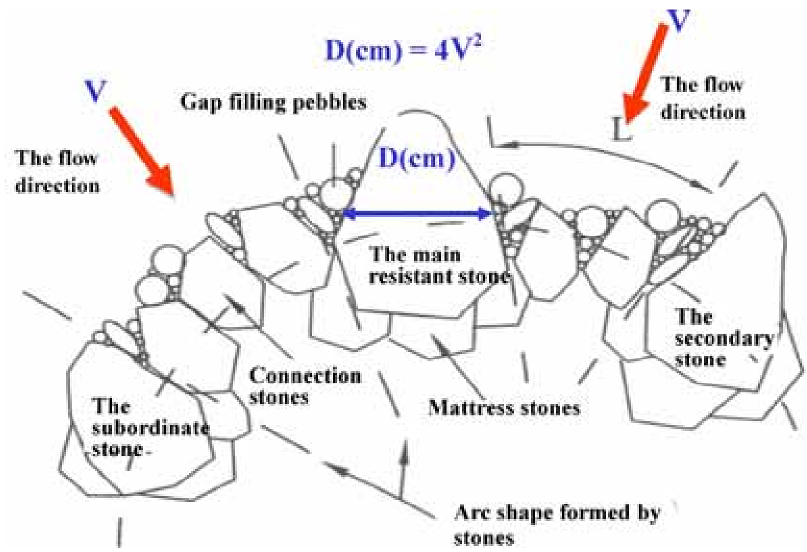

Fig. 10 – A design of arc-shape stone streambed sill (modified from Syubun, 1995).

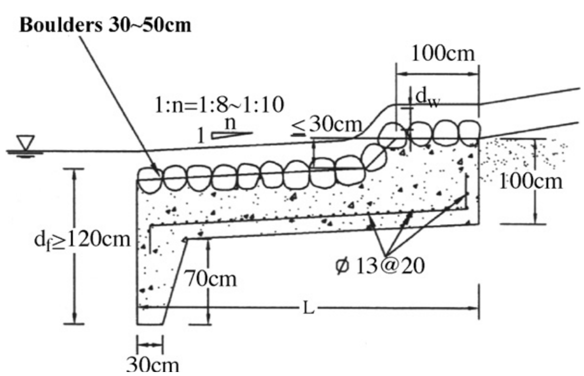

Fig. 11 – A slant streambed sill (SWCB, 2002a).

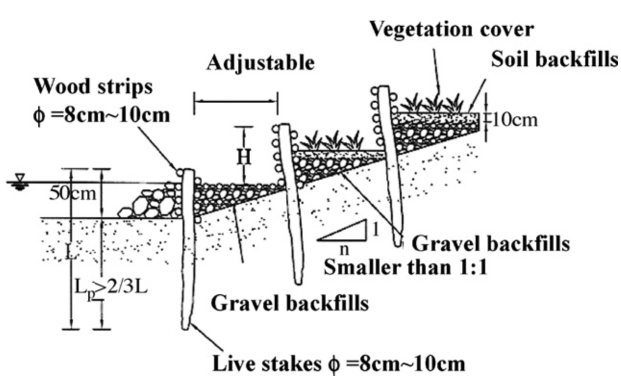

Fig. 12 – Landslide source control with staking and wattling (SWCB, 2002a).

5. Inspection of the ecological engineering methods in Taiwan

Properly designed ecological engineering methods are effective for restoration of ecosystem. During planning and design stages of mitigations, the factors such as safety, ecology, landscape, geomorphology, and hydrology were considered by the SWCB. It was found that the ecosystems reinstate gradually after using the ecological engineering methods. Through the two-year ecological investigations directed by SWCB (2003a) for Liu-chung Creek in Tainan, Mu-dan Creek in Taipei County, and Tou-bain-keng Creek in Taichung County, with the ecological engineering methods using gentle slope, porous revetments and reducing obstacles in ecological corridors, the quantity of aquatic insects obviously increased, and fish and shrimp have returned to the streams. In addition, butterflies and fireflies live in it after the mitigations. This is the most solid benefit to the ecosystem. The SWCB is proposing more ecological investigations for those areas treated by the ecological engineering methods to study the effect of the methods to environment.

The average annual rainfall of the world is about 500 mm. However, the rainfall in Taiwan is from 2500 to 3000 mm annually. During Typhoon Mindulle (2 July 2004), within only three days, the abnormal high rainfall was measured up to 1159 mm in central Taiwan, and up to 2066 mm in southern Taiwan, nearly the average annual rainfall of Taiwan. On 24 August 2004 there came Typhoon Aere, which caused many mitigation works applying ecological engineering methods to be damaged. Therefore, it is obvious that the ecological engineering methods implemented in Taiwan should be localized to comply with the extreme high average annual rainfall. Stronger and safer designs will be necessary; the localized ecological engineering methods developed will be somewhat stronger and sometimes can be very different from those designed in Europe, USA, and Austria (FISRWG, 1998; Gray and Sotir, 1996; Li and Eddleman, 2002; Hsieh, 2004).

After the Chi-Chi earthquake in 1999, the SWCB paid more attention to the aspect of safety and ecology in mitigating of streams. Some projects, constructed by ecological engineering methods, were still safe and stable during the calamity of heavy rainfall in Typhoons Mindulle and Aere. Field reconnaissance determined that about ten streams in which mitigations using ecological engineering methods were just complete, survived the severe flooding of Typhoons Mindulle and Aere. Only some arc-shape stone streambed sills were locally damaged.

After Typhoons Mindulle and Aere, there were 821 projects (a total of 390 ha) treated with the landslide source control with staking and wattling method had been inspected. Only 164 projects showed damage (102 slight damage and 62 serious damage). The damage area is about 58 ha. Therefore, the effective stabilized area is more than 85%. The 15% damage area mostly showed local scouring or collapsing caused by the tremendous rainfalls. However, there was no major hazard such as debris flow and large scale landslide. This also proves the effectiveness of the landslide source control method. In Fig. 13, different effects can be observed for areas with and without the landslide source control treatment. Generally, landslide areas after the treatment will have a faster re-vegetation rate and better stability, thus creating more protected habitats with biodiversity.

Fig. 13 – A comparison showing the effect of staking and wattling erosion source method.

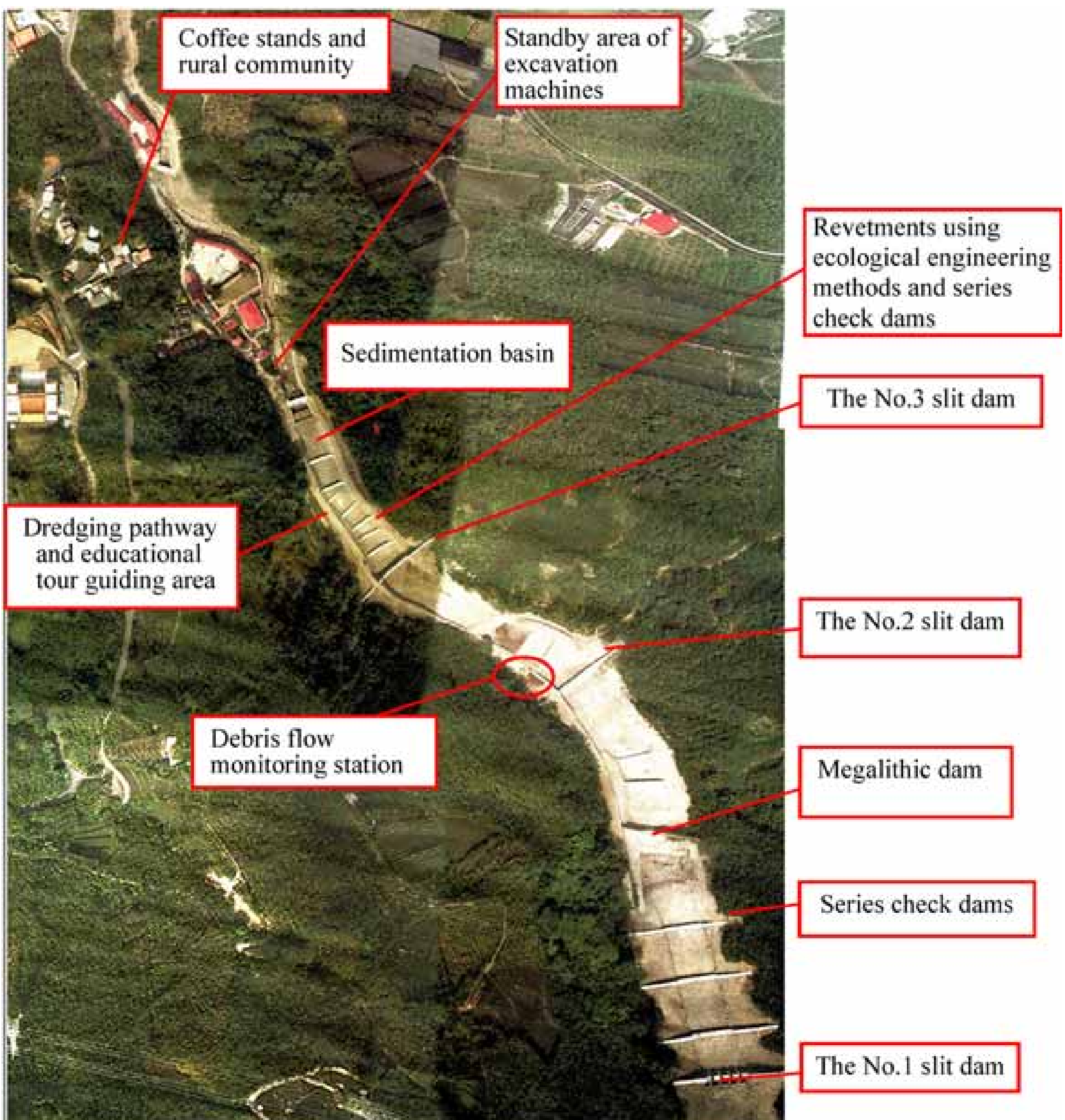

Fig. 14 – Layout of the integrated mitigation of the Hua-shan debris flow area.

6. Integrated mitigation for debris flow Torrent—an example of Hua-shan Creek in Gu-keng County, Taiwan

Hua-shan Creek is not a perennial stream. Water flow only appears during heavy rainfall for a couple of days. Therefore, the aquatic life form in the creek is very rare. The geological condition in the watershed of Hua-shan Creek is generally unstable with high potential of debris flow. The mitigation for the creek considered safety first, and ecology second. The disasters of the debris flows were triggered by a heavy rainfall event in 2000 and Typhoon Toraji in 2001. As a result, the stream channel was eroded into 50–60 m wide. Some sections of the stream reached a hundred meters wide. The streambed was raised up, ranging from several meters to more than 20 m. The sediments on the streambed were also unstable. From investigations, Hua-shan Creek shows the characteristics of debris flow torrent, i.e. the source zone, transportation zone, and deposition zone.

There are few residents in the Hua-shan Creek area. Relocating people will be the long-term safety solution because there is no omnipotent engineering method that can ensure the safety of people living in a dangerous habitation. However, due to important indigenous cultures and for rural development, the inhabitants, the government, and SWCB concurred to commence the integrated design of the mitigation for Hua-shan Creek.

The major mitigation of Hua-shan Creek (Fig. 14) is presented as follows (SWCB, 2004; Wu, 2002a, 2002b, 2002c, 2002d):

(1) Source zone: For treatment of landslide source zone, it is necessary to investigate the locations, possible sliding areas and volume of the landslide first. The landslide source control with staking and wattling method mentioned previously was adopted.
(2) Sedimentation control: It is often found that the streambed is eroded seriously in both vertical and horizontal directions after debris flow occurrence. As a result, the streambed could remain unstable and easily induce sliding. It provides the source of sediments which can be transported to downstream and again erodes the streambed. The scenario repeated from upstream to downstream periodically. For sediment control, series of low check dams were used for applying ecological engineering methods. Although these low dams may be easily filled up, they raised the streambed which can stabilize toe of slopes. The application is demonstrated in the upstream of the Hua-shan Creek.
(3) Transportation zone: In this zone, slit dams and a series of low check dams were adopted to reduce the energy of debris flow as well as erosion of streambed. Application example is demonstrated in Figs. 15 and 16 for the No. 1 and No. 2 slit dams, stone dam, and a series of low check dams.
(4) Deposition zone: In this zone, the slit dams and sedimentation basin based on the ecological engineering methods were designed. The vegetation was applied in the wide-open streambed. An application example is shown in Fig. 17 for No. 3 slit dam. Due to limitations while acquiring the land, a large sedimentation pond was not possible in this project.
(5) Dredging pathway and educational area: The debris flow area after mitigation is planned as an educational park.

Fig. 15 – The No. 1 slit dam and series check dams.

Fig. 16 – The No. 2 slit dam and dredging pathway.

Fig. 17 – The No. 3 slit dam and stone revetment.

The sidewalk in the left bank was used as recreational area and for the study of ecology. The sidewalk will also be used as a dredging pathway if future debris flow occurs. To quickly drain rainfall water, coarse gravels are built on the sidewalk. Also, stones were used for the guardrails instead of concrete. Together with the hillslope vegetation, the dredging pathway provides a compromise between leisure recreation and engineering (Fig. 16).

(6) Debris flow monitoring station: A debris flow monitoring station was established to monitor the possible debris flow and to provide the data for research and education (Fig. 16).
(7) Culture and landscape: After finishing the mitigation of the Hua-shan Creek area for the debris flows, new buildings, coffee culture, and local arts will gradually develop. The area becomes a popular recreational spot in Taiwan.

Hua-shan Creek experienced Typhoons Mindulle (2 July 2004) and Aere (24 August 2004) and successfully withstood the severe consecutive tests of floods (Fig. 18). The success is due to the integrated mitigation strategy based on ecological engineering methods, including landslide source control with staking and wattling, stone revetment, stone streambed sill, and the conventional slit/check dams with ecological considerations. The mitigation greatly reduced the transportation of sediments. As a result, the storm water flow is clear and the hillslopes become successfully vegetated. The streambed also becomes a naturalized habitat for frogs, insects, butterflies, and birds.

Suffering from the earthquake disasters in 1999 and debris flows in 2000 and 2001, Huashan Village was severely damaged, becoming a desolate area. With lessons learned from nature, the village has been reconstructed/rehabilitated and integrated with environment friendly methods for disaster prevention, recreation infrastructures, habitat improvement, and for rural community management. It is now becoming a new recreation attraction and the name "Hometown of Taiwan Coffee" of Huashan spreads all over the country. The prosperity of the Hua-shan area is a great evidence of successful implementation of the ecological engineering principles.

Fig. 18 – Hua-shan Creek had passed the server consecutive flooding examinations.

7. Integrated mitigation for a stream—an example of Ding-zi-lan-keng Creek in Taipei County

Ding-zi-lan-keng Creek was planned to protect its original pools and shoals, to create more riffles, torrents, turbulences, slacks, and backwaters using ecological engineering methods, and to enhance stream functions for various aquatic and terrestrial animals. Scenery recreational function for human was also considered (SWCB, 2003c).

The major mitigation of Ding-zi-lan-keng Creek is described as follows:

(1) The integrated design (Fig. 19): the mitigation plan for Ding-zi-lan-keng Creek is divided into water source protection area, ecological protection area, the ecological experience area and the recreation areas (the Qin-shui Bridge), mitigation area (including check dams, landslide source controls, and revetments), historical protection area, scenery suspension bridge, pavilions, pedestrians, wetland, and vegetation buffer zones.
(2) The sedimentation mitigation: Ding-zi-lan-keng Creek shows characteristics of landslide and streambank erosion in its upstream. To consider both safety and habitats, the stability of the streambed is increased by the ecological engineering methods.

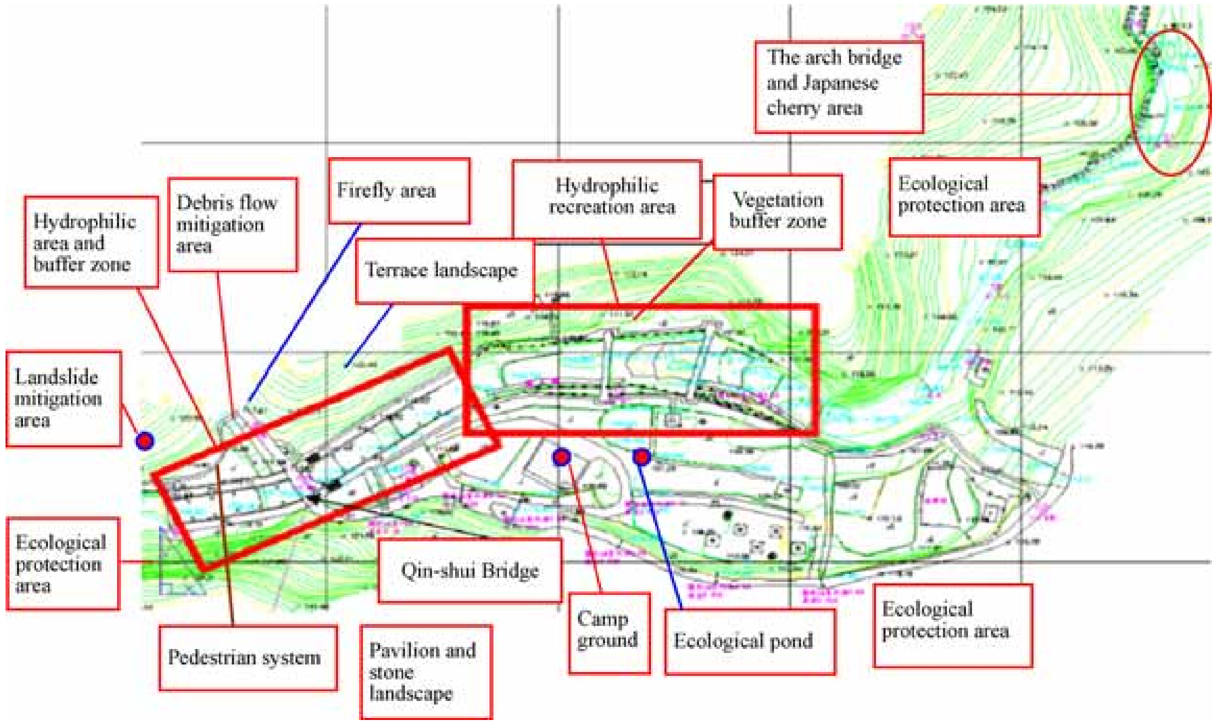

Fig. 19 – Layout of the integrated mitigation of Ding-zi-lan-keng Creek.

(3) The ecological protection area: To maintain the original features as much as possible and avoid interfering with amphibious animals, any residential development is forbidden.
(4) Ecological buffer zones: Two buffer zones are designed for lower frequency of recreation activity. They control excess interference to amphibious animals and the nearby habitats.
(5) Vegetation buffer strips and habitat protection: Vegetation buffer strips can reduce the temperature of water, supply fragments of plants to improve habitat environment, decrease pollutants such as sediments, toxic matters and pesticide, etc. The strips also provide functions including filtering, absorbing, purifying, and supply amphibious animals a good environment to grow. Artificial wetlands were constructed to prevent pollution from accumulation.

Fig. 20 – The recreation area.

(6) Ecological experience and ecological protection area: To let people get an ecological experience without interfering in the ecology too much, low–density and minimum structures were planned. The observation routes for aquatic animals were built according to the local topography to minimize the quantity of cuts and fills.
(7) Recreation area: Washout and landslide occurred at the downstream of Ding-zi-lan-keng Creek. It was mitigated with stone revetment, streambed sills, and arc-shape stone streambed sills to create natural aquatic zones and gentle sloping streambanks (Fig. 20).

Ding-zi-lan-keng Creek is not a debris flow torrent, therefore the stones in the streambed are not enough for the ecological engineering methods. Only about 30% of the stones used are from the creek, and the other 70% were purchased from another source. There are various bio-environments in Ding-zi-lan-keng Creek which is a significant biodiversity area for aquatic animals. In order to reduce the significant change in the environment, original features were maintained as much as possible with the ecological engineering methods for mitigation. The integrated mitigation design has experienced Typhoon Aere and survived from flooding (Fig. 21).

8. Challenge for promoting ecological engineering method in Taiwan

(1) Difficulty of land acquisition: More land is usually required for general approaches of ecological engineering methods such as gentle slope for streambank protection, sabo dam,

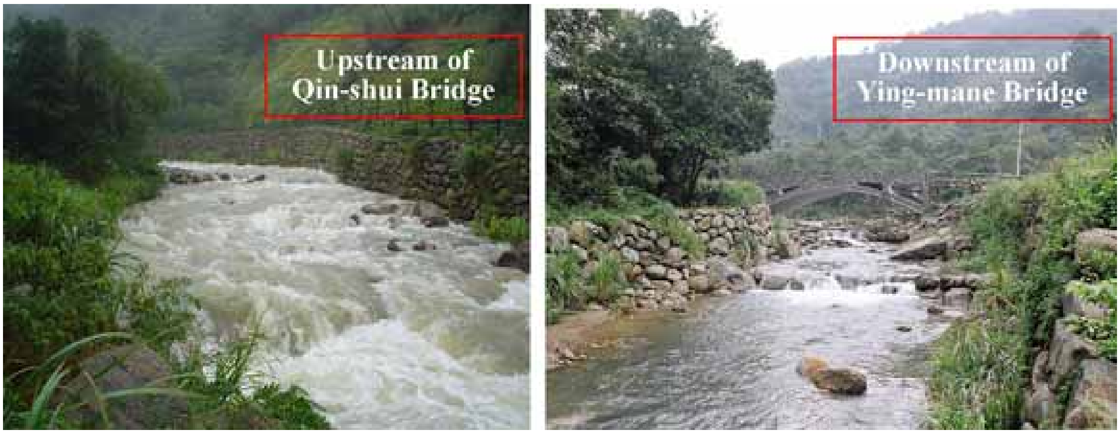

Fig. 21 – After Typhoon Aere (24 August 2004), Ding-zi-lan-keng Creek had passed the server test of flooding.

pool, and shoal, but it is difficult to acquire enough land in Taiwan.

(2) Large number of habitats to be improved: Conventional engineering work such as concrete dams and concrete revetments that could impact the ecological environment needs to be improved. However, the number of those facilities is significant. How to systematically perform habit improvement is a challenge.

(3) Lack of natural resources and its countermeasures:
   a. Due to the unique topography and rainfall intensity characteristics in Taiwan, stone-paved work is often selected for its better durability and stability. However, the lack of stones and wood logs is a common problem in Taiwan.
   b. The countermeasures should include: Establish storage facilities for stones; delimit specific areas to mine usable stones; import stones or other natural materials; and encourage civilian investment in developing artificial stones and wood logs.

9. Concluding Remarks

Due to the high average annual rainfall and special landforms of Taiwan, the promotion and application of the ecological engineering methods are more difficult than other countries. It is better to develop localized ecological engineering methods complying with the special geological, hydrological, and environmental conditions of Taiwan. For soil and water conservation and sustainable development, we should deem the ecological engineering methods as a general guideline and apply more "flexible" treatments together with engineering, agronomic, and vegetation measures.

The mitigation strategy of the hazards of streams and gullies on hillslopes should be an integrated plan by taking their watersheds as a unit with investigations including ecological resources, landslide and debris flow hazards, non-point source pollution, and local culture. It is also important to involve the participation of local residents, experts, scholars to come up with suitable ecological engineering methods that fit most of the habitat requirements.

Only enough investigation, comprehensive planning, diligent construction, and management in ecological engineering methods could build the diversified habitats and create a high-quality environment with respect to completeness, ecology, culture, and local characteristics. Therefore, humans and the environment can coexist harmoniously and also biodiversity and symbiosis can be highlighted.

Starting from the integrated design for watershed and using both innovative and practical techniques, we can apply the ecological engineering methods as the foundation for hazard prevention and mitigation. Along with the continual enhancement in ecosystems, a better living environment can be achieved.

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