坡面排水與打樁編柵之
源頭治理方法與敏督利颱風後之成效評估

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摘要

本研究介紹表面排水與打樁編柵等台灣常用之沖蝕控制方法，藉由設置表面排水、坡頂裂縫填補及植生，可大幅降低表面沖蝕與降雨入滲土壤等現象發生。因此，經處理後僅有少量降雨會入滲增加邊坡的不穩定性。表面排水能降低蝕溝沖蝕，打樁編柵配合植生應用於邊坡能增加坡面植生的再生速率，在坡趾處可依需求設置排水管，降低地下水位上升的機會。藉由敏督利颱風後對所處理的方法進行驗證，證實此方法能有效控制沖蝕。結果顯示只有 9.4% 的工址因颱風豪雨而遭受損壞，超過 90% 的工址仍保持穩定，並且沒有嚴重土石流災害和大規模崩塌等現象發生。因此，對崩塌潛勢較高之區域以沖蝕控制方法進行處理是相當有效的。

（**關鍵字**：沖蝕控制、排水、打樁編柵）

An Evaluation of the Erosion Control Method with Slope Drainage, Staking and Wattling in Taiwan after Typhoon Mindulle

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ABSTRACT

This study evaluated the effects of one of the slopeland erosion controls, Surface Drainage, Staking and Wattling (SDSW) that is commonly used in Taiwan. The SDSW erosion control includes installing surface drainages, re-vegetation and filling cracks around the top of the control areas. The

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SDSW erosion control was theorized and intended to greatly increase the land stability by reducing rainfalls from sipping into subsurface of the control areas. The surface drainage is to reduce sheet/gully erosion while staking and wattling is to increase re-vegetation of the land surface. Wherever appropriate or required, drainage pipes can be installed at the slope toe to reduce the water build up. The evaluation of SDSW erosion control was based on a survey of land erosion right after the Mindulle Typhoon in the areas where the SDSW erosion control had been in place. Based on the survey, only 9.4% of the sites with the SDSW erosion control has experienced significant local scours or landslides while the remaining sites have sustained neither major debris flow or large scale landslides. We were pleased to see that the SDSW erosion control has been proven and validated to be a very effective slopeland erosion control.
(**Keywords**：erosion control, drainage, staking and wattling)

1. INTRODUCTION

The Chi-Chi earthquake (M_L=7.3) in September 21, 1999 struck Taiwan, causing an 80 km surface rupture, the Chelunpu fault. The horizontal acceleration monitored was as high as one gravity (980 gal) with strong up-down shaking also (1). This caused numerous landslides in central Taiwan. Due to the active tectonic movement, the geological formations of Taiwan's mountain are complex and mostly fractured. In addition, Taiwan is located in the path of tropical typhoons which bring tremendous rainfalls almost every year during summer. The average annual rainfall of the world is about 500mm. However, the rainfall in Taiwan is from 2500 to 3000mm annually. Therefore, after the earthquake and typhoons during summer, many of the mountain slopes were remained unstable and subject to fall/slide.

The erosion control method developed in Taiwan was encouraged by the government for landslide source area treatment (2). This method uses surface drainage system to cutoff/drain runoffs and to fill cracks on the top of landslide area. It can greatly reduce the amount of rainfall entering the landslide prone area thus increases stability. Staking and wattling is applied on slope face to increase re-vegetation rate. Endemic plant species can be replanted first with carefully selected alien plant species or avoided. Drainage systems and vegetation can reduce sheet/gully/rill erosion. At the slope toe, drainage pipe can be installed to lower the water table to increase stability. Engineering measures, such as soil nails and retaining work can also be added if necessary to secure a stronger mitigation. The method is modified from the "soil bioengineering" for stabilization of soil and rock cut slopes proposed by Sotir and McCaffrey (3).

In Taiwan, erosion control is usually carried out by rural village residents or even landslide victims. The philosophy behind is that the victims can find new courage for life, and for villagers to treasure their own lands and live in harmony with nature. The method is more environmentally friendly than conventional mitigations. It applies natural materials, nurse native plants, combines herbaceous and arborous plants and afforests complex vegetation layers. It is expected that with this method the "ecological" succession time for vegetation to be stable is much faster than that of natural succession. Benefits of the method include cost savings, air pollutant uptake, and carbon dioxide sequestration (4).

Generally, landslide areas after the erosion control treatment will have less erosion rate and better stability. During Typhoon Mindulle (July 1~4, 2004), within only three days, abnormally high rainfall measured up to 1,200 mm in central Taiwan, and up to 2,000 mm in southern Taiwan, or nearly the average annual rainfall of Taiwan. This typhoon provided chance for examining the performance of the erosion control method. The inspection result shows that the method is a relative effective mitigation method for landslide areas and barren slopes.

When slope is treated with this method, the cracks are supposed to be filled and runoff on slope face should be reduced in a great amount. Rainfalls infiltrating into the slope body may cause stability problem of a slope.

Figure 1 shows that the path of Typhoon Mindulle and the isohyets of the induced rainfalls. The site of Jiu-fen-er-shan is shown with a solid triangle. In the Figure, the intensity contours of 1999 Chi-chi earthquake, epicenter, the Chulunpu fault, and where the sites treated with the erosion control method are all shown. It can be observed that in central Taiwan it is "ravaged" by the earthquake and typhoons.

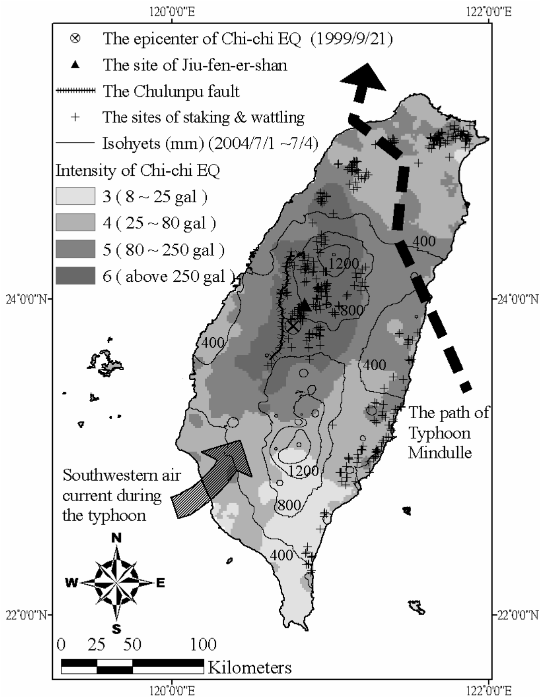

圖 1. 沖蝕控制處理工址及九份二山位置套疊敏督利颱風等雨量線與集集地震強度等勢能線

Figure 1. Sites adopting erosion control method and Jiu-fen-er-shan with Typhoon Mindulle isohyets and Chi-chi earthquake intensity contours.

2. EROSION CONTROL METHOD WITH DRAINAGE, STAKING AND WATTLING

2.1 The Method and Treatment Strategies

Normally a landslide and unstable slope have some cracks on top of the slopes.

There may be tree dangling on slope face. Runoffs cause sheet/gully/rill/inter-rill erosion; and there are deposits near toe of slopes as shown in Figure 2. The method includes three major strategies of treatment, as following and is shown in Figure 3 & 4.

- Erosion source treatment on top of slope: backfill cracks, build lateral drain ditches, clean dangling trees, etc.
- Slope surface treatment: construct lateral and longitudinal drain ditches, perform staking and wattling (Figure 5), vegetate, etc.
- Treatment at toe and deposits: build toe ditches, construct soil nails, construct gabions, drill drainage pipes in slope toe, replant buffer zone, etc.

If tension cracks on a slope are not treated and are filled by rainfall water, the groundwater table would be raised higher (Figure 6a). This will cause the slope materials to softening, reducing shear resistant strength (resistance) and increasing self-weight (driving force) of the slope. The safety factor of the slope will be greatly reduced. However, if the cracks are treated with fillings that prevent water from entering the slope (Figure 6b), the groundwater table would only be raised by infiltration and remains at a much lower level. The slope could have a relatively better stability.

2.2 Drainage Treatments for Slopes

The basic principle for drainage is to prevent water from entering the landslide slope. Various drainage facilities can be used to fulfill the needs, such as longitudinal and lateral drainage ditch, waterfall, drainage pipe, etc. More environmental friendly treatments such as grass ditch, stone ditch, backfill-bag ditch, etc. Figures 7a~7d show some of the practical application of installing a drainage system for a slope on top, on the surface and at the toe.

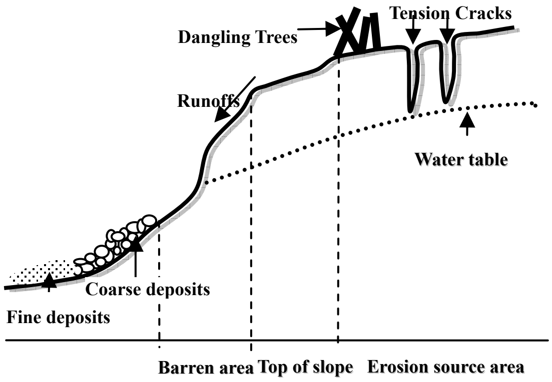

圖 2. 崩塌地與不穩定邊坡問題示意圖
Figure 2. Problems of a landslide and unstable slope.

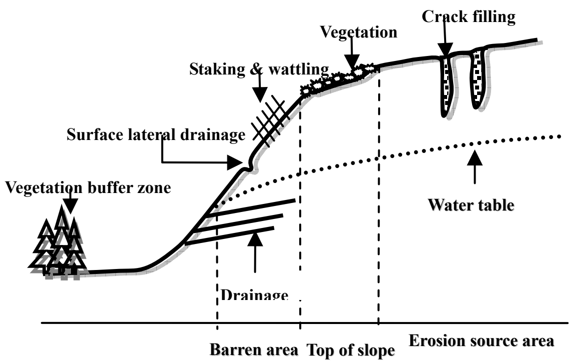

圖 3. 邊坡沖蝕控制處理示意圖
Figure 3. Treatment of the erosion control method.

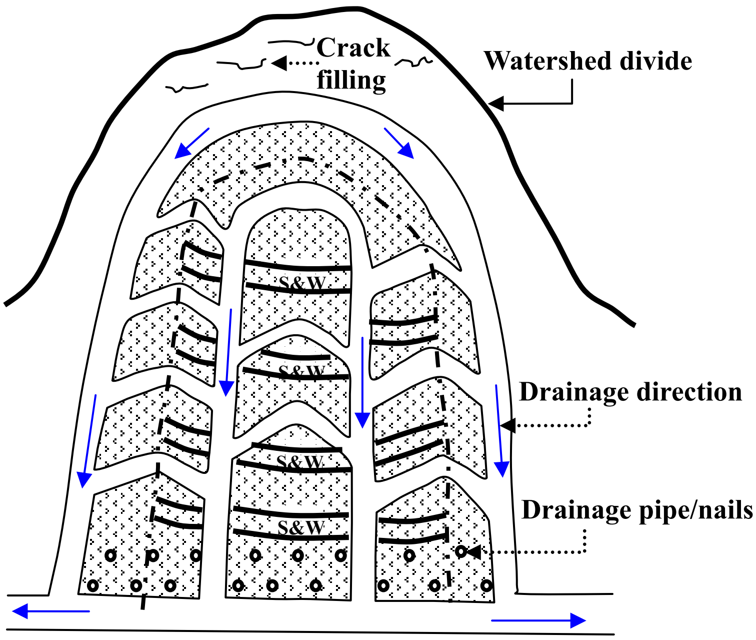

圖 4. 邊坡沖蝕控制處理正視圖
Figure 4. Front face of the slope treated with the erosion control method.

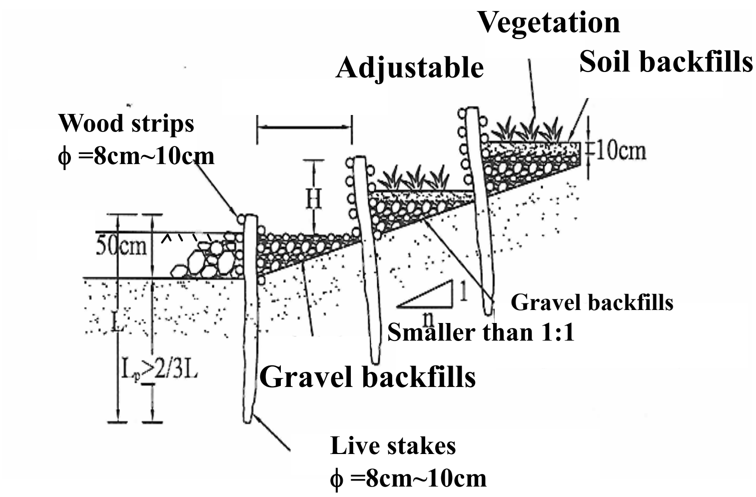

圖 5. 坡面打樁編柵示意圖 (2)
Figure 5. Staking and wattling on slope surface (2).

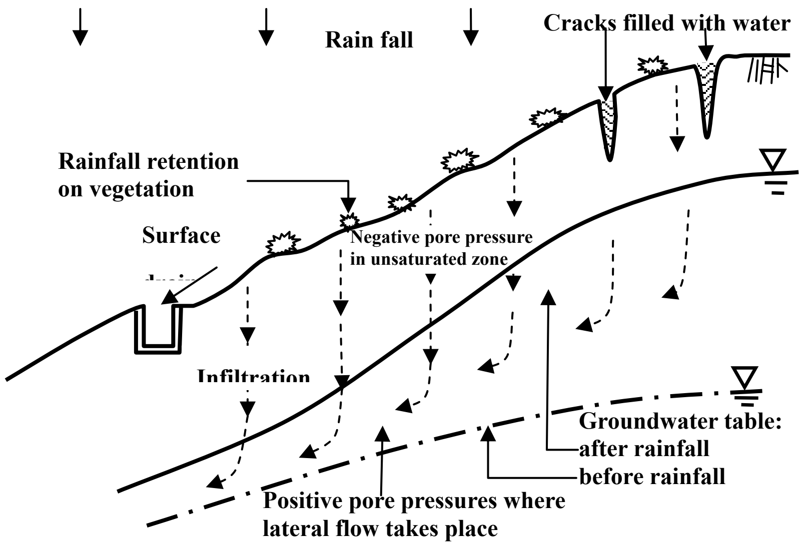

圖 6a. 邊坡未填補裂縫降雨入滲情形與可能地下水位示意圖

Figure 6a. Infiltration on slope and possible groundwater table after rainfall – before filling cracks.

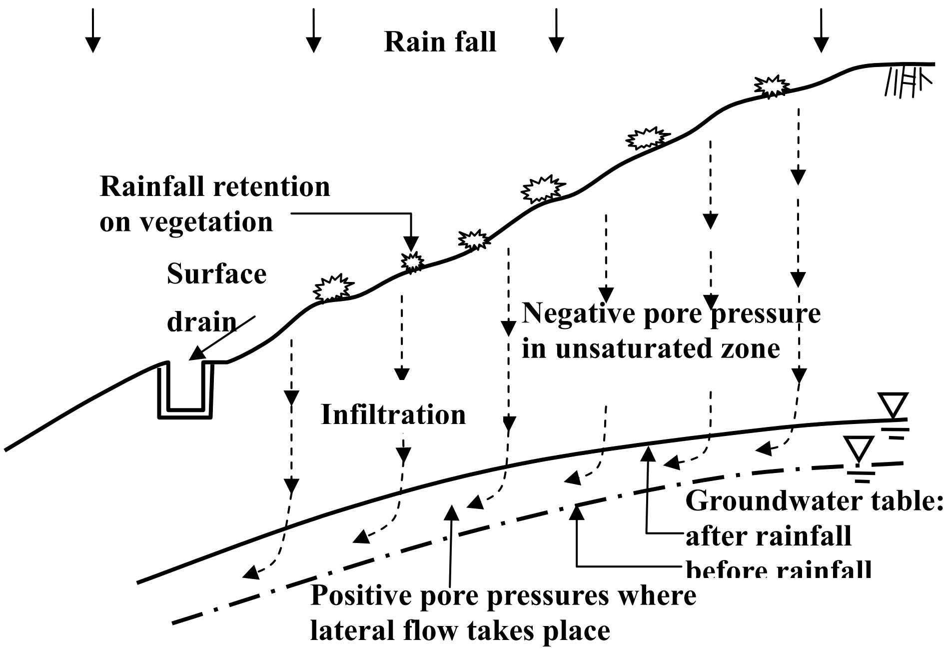

圖 6b. 邊坡填補裂縫後降雨入滲情形與可能地下水位示意圖

Figure 6b. Infiltration on slope and possible groundwater table after rainfall – after filled cracks.

圖 7a. 邊坡坡頂回填透水材料截水 (5)
Figure 7a. Water cutoff at top of slope by backfilling(5).

圖 7b. 採用自然資材設計之疊水工 (5)
Figure 7b. Waterfall using natural materials (5).

圖 7c. 坡趾掘溝排水 (5)
Figure 7c. Ditch at toe (5).

圖 7d. 坡面背填土袋橫向排水與植生 (5)
Figure 7d. Backfill-bags for lateral drainage and vegetation on slope surface (5).

The design of the ditch is mostly based on “rule of thumb”. However, detail calculations for the ditches can be completed using Manning’s equation when necessary. Note that lateral drainage should be less than 2 degrees in order not to damage the slope again. Pools of water should be avoided to reduce failure possibility of drainage works. The length of longitudinal drainage should be increased as long as possible to reduce sloping and energy dissipation works such as waterfall should be added. It may be necessary to meander the longitudinal drainage work. Large drainage works may be required beneath the cliff and upper zone of an alluvium.

2.3 Drainage in Toe of Slope and Stability Measures

It is common to use horizontal drainage pipes to lower groundwater level for toe drainage at a landslide prone slope. Structure works, such gabion, stone wall, concrete crib wall, and soil nails can be installed to further increase the stability of the slope and with good drainage.

3. PERFORMANCE OF THE EROSION CONTROL METHOD

3.1 Ecological and Aesthetic Effect

Properly designed erosion control method can be effective in stabilization a landslide area and restoration of a local ecosystem. During planning and design stages of mitigations, factors such as safety, ecology, landscape, geomorphology, and hydrology should be comprehensively considered. It is often found that after a landslide area is stabilized, the ecosystems reinstate gradually after using the erosion control method(2). A successful example site in Sanwan Xiang, Taiwan, adopting the erosion control method is shown in Figure 8a~8c for before, during and after the construction. The landscape scene after re-vegetation is satisfied. Figure 9 shows a comparison between with and without the erosion control method at a same site. It is obvious that the part with the treatment is stable and re-vegetates very well without further erosion.

3.2 Performance Checks by Field Inspections after Typhoon Mindulle

After the Chi-Chi earthquake in 1999, the Taiwan's Soil and Water Conservation Bureau paid more attention to the aspect of safe and ecology in mitigating landslides. The lesson is learned, that the methods implemented in Taiwan should be design to comply with the extreme high average annual rainfall. A stronger and safer design than those soil bioengineering developed in U.S.A. or Europe should be necessary for Taiwan. During Typhoon Mindulle (July 1~4, 2004), the abnormally high rainfall was measured up to 1,200 mm in central Taiwan, causing many mitigation works which applied the erosion control method to be damaged.

圖 8a. 崩塌地處理現址–施工前(三灣鄉)
Figure 8a. A landslide site before construction (Sanwan Xiang, Taiwan).

圖 8b. 崩塌地處理現址–施工中(三灣鄉)
Figure 8b. During construction.

圖 8c. 崩塌地處理現址–施工後(三灣鄉)
Figure 8c. After construction.

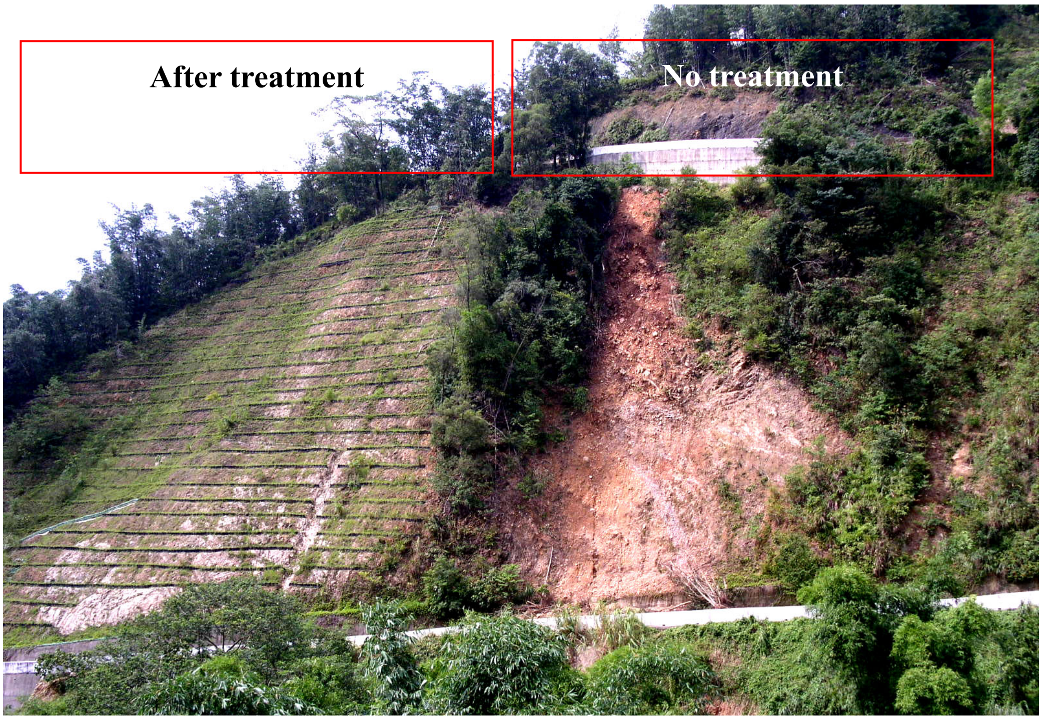

圖 9. 邊坡進行沖蝕控制處理與未處理影響比較 (2)
Figure 9. A Comparison of the Effect of the Erosion Control Method (2).

Most projects constructed by the erosion control method were still safe and stable during the calamity of heavy rainfall in Typhoons Mindulle. Field inspections after the typhoon show that the performance of the method is satisfied. As shown in TABLE 1, there were 4185 projects treated with the erosion control method with surface drainage, staking and wattling had been inspected. Only 149 projects showed severe damage and 243 projects with slightly damage. Therefore, the effective stabilized areas are more than 90%. The damage projects (9.4% of the total) 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 and no casualties. This proves the effectiveness of the method. In addition, landslide areas after the treatment will have a faster re-vegetation rate and better stability, thus creating more protected habitats with biodiversity. Comparing with the conventional method with 2.8% damage that uses concrete as the major material for mitigation, the conclusion can be again drawn that the performance of the erosion control method is superb in terms of economical, safe, ecological and local cultural aspects.

表1. 治理工作受敏督利颱風損害統計表
Table 1. Damage of Mitigation Works after Typhoon Mindulle.

Method	No damage (A)	Slightly damaged (B)	Severe damage (C)	Debris flow	Casualty	Total D= (A+B+C)	Damage ratio (B+C)/D
Erosion control method	3,793	243	149	0	0	4,185	9.4%
Conventional method	3,032	73	15	0	0	3,120	2.8%
Total	6,825	316	164	0	0	7,305	6.6%

[1]This table was made after the Typhoon Mindulle by investigating the sites mitigated with the erosion control method and conventional method done during 2001~2003.

[2]The conventional method uses concrete as the major material for mitigation; therefore, the damage is less than the erosion control method.

3.3 Influence of Geological Conditions on the Erosion Control Method

Wu (6) performed field surveys for 91 sites with staking and wattling method for vegetation coverage based on geological formation and soil types. He concluded that alternated sandstone/shale and sandstone formation are not suitable for the staking and wattling method. Also, the silt loam and silt soil types are not recommended.

This study continues to collect sites where damages occurred after typhoons. Additional comparisons can be made for geological condition and soil types when the amount of the sites is enough. The coordinates of damage sites can be further overlapped in Geographical Information System with geological and soil layers, similar to Figure 1, to compare their relationships. Percentages of damages in each geological formations and soils types then can be calculated (7).

4. CONCLUSIONS

This study evaluates the erosion control method with surface drainage, staking and wattling used in Taiwan. This method includes installation of surface drainage system, cracks fillings, and re-vegetations. It intercepts a great amount of slope surface runoffs and reduces erosion. Only little infiltration goes into the slope. At the slope toe, drainage pipes or soil nails, structures can be constructed to increase stability. The effectiveness of the erosion control method has proven by inspecting the performance of the sites treated with the method after Typhoon Mindulle in July 2004. The effectively stabilized areas are more than 90%. Inspection results show that the erosion control method is an effective mitigation method for landslide areas and barren slopes.

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