Sustainable Rehabilitation of a Highway Slope Failure with Geosynthetics

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ABSTRACT*:* This paper presents a novel solution by taking into account of safety and sustainability to cope with a damaged slope. The rehabilitation consists of a piled supported reinforced concrete protection wall and a reinforced soil slope (RSS) with geosynthetics. Such approach is not common; however, the experience described herein has shown that the reported composite retaining structure meets all the site criteria. RSS demonstrated competent safety and significant carbon footprint reduction compared to those of traditional reinforced concrete structures. RSS also successfully made a vegetated terrain that has presented a natural appearance and provided an aesthetic and eco-friendly environment for the site. Based on field observations, the slope is stable and safe to date. It is a valuable and sustainable solution particularly for those sites that have a major concern with basal instability due to scouring effect.

Keywords: sustainability, geosynthetics, reinforced slope, scouring

1 INTRODUCTION

The effect of global warming has prompted the management of carbon emission to be an important issue for constructions around the world. The productions of the construction industry in the total annual global green-house gas (GHG) emissions has been significant and immediate preventive measures are required for environmental concerns (IPCC 2007). GHG emissions are usually reported in carbon dioxide equivalent (CO_2-e) units and, for simplicity, are generally referred to as carbon emissions. A carbon footprint is defined as the total set of greenhouse gas emissions caused by an individual, event, organization, or product, expressed as carbon dioxide equivalent. The emissions associated with a structure occur in different phases of its life cycle including material extraction, transportation, construction, operation and end-of-life phases (Zahra et al. 2015). For example, traditional design of retaining structures using reinforced concrete can have severe GHG impacts because of the productions of materials and the way of construction. In addition, it also frequently leaves behind a stark legacy of a bare structure unsuitable for wildlife and unsightly for local residents. This paper presents a case study of slope rehabilitation by take into account not only the safety of the structure but also the carbon emissions of construction and thereby to achieve a sustainable solution for the project.

Route 9 is the most important arteries in southern Taiwan with world-famous natural scenery along the line. In August 2013, Typhoon Kongrey hit the island with heavy rainfall and caused numerous infrastructure damages in these areas. As shown in Figures 1~2, the site reported herein located at Sta. 470k+500 where its downslope was totally collapsed due to the riverbank breach which was smashed by the rushing flooding of the adjacent River. The in-situ drainage system also was found insufficient to accommodate the enormous overflow came from the upper land of the site. The highway was seriously disrupted and the rehabilitation was immediately necessary to resume the normal livelihood of residents and minimize the loss of local tourism productions.

The depth of the slope was over 20 m and the toe was vulnerable by the attack of the adjacent river. There were tons of rubbles on site because of the collapsed debris and they must be used as much as possible for construction as the highway managing authority required the rehabilitation should be a sustainable solution. The final completed structure should be durable, aesthetic, and eco-friendly. In addition, the owner also required the construction must be completed within a limited schedule

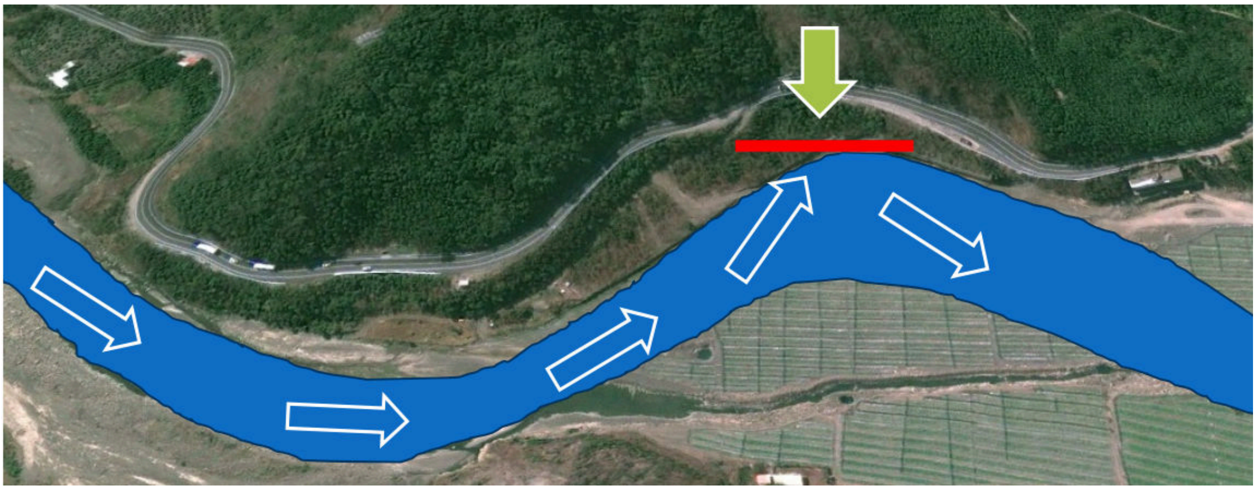


Figure 1. Site location.

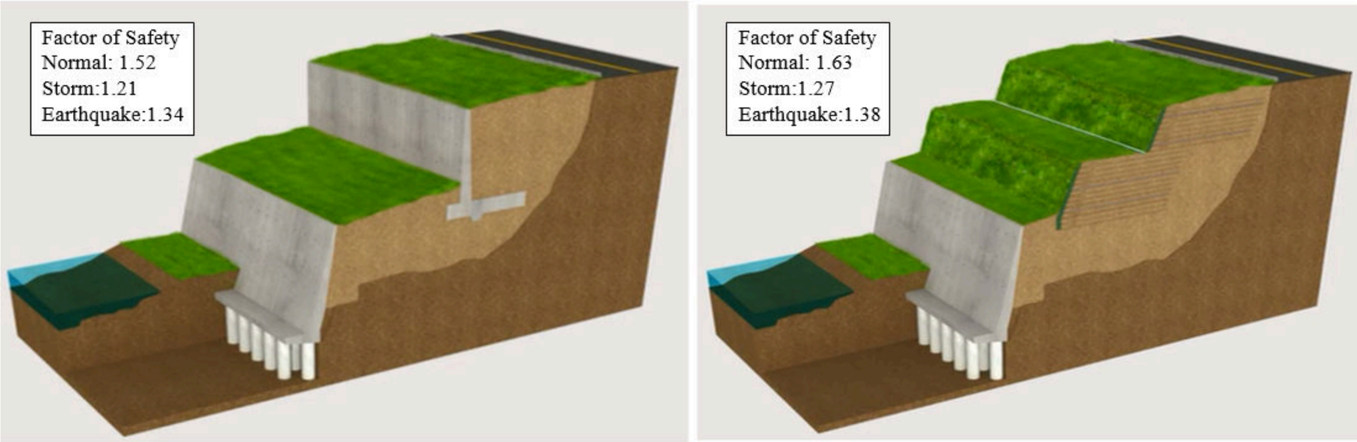
Figure 2. Severe scouring smashed the riverbank and caused disruption of the highway.

2 DESIGN AND CONSTRUCTION

2.1 *Design considerations*

The design of rehabilitation for a damaged slope usually starts by making a number of decisions including selection of the retaining structural system. The three most important characteristics considered generally include stability system, available materials, and ease of construction. Such decisions are usually made by geotechnical engineers, in close collaboration with owners, by taking into account a number of selection criteria which address the performance, costs, construction schedule and any other requirements outlined by project managing committee.

The traditional solution for the case reported herein would be simply building a staged cast-in-place reinforced concrete (RC) retaining walls and then backfilled in layers with qualified imported materials to the elevation of the pavement. However, it would be the same as before, the retaining wall on a shallow foundation would most likely be destroyed again by violent floods. Pile foundations, therefore, must be used to support the structure so that it can stand firmly on the steep slope and provide sufficient protection for river scouring (Figure 3a). Although sustainability and management of carbon emissions are the required missions for this project, stability must be warranted to assure public safety. To improve the adverse effect of concrete structures, the designer proposed to use geosynthetic reinforced soil slope (RSS) to replace the upper retaining structure (Figure 3b). As can be seen in Figure 3, both design schemes presented comparable safety condition. RSS has been successfully used worldwide for the past decades to stabilize slopes with high merits in sustainable and eco-friendly environment (FHWA 2009).



(a) Traditional RC retaining wall. (b) Reinforced soil slope.

Figure 3. Proposed design schemes and their safety evaluation.

2.2 *Construction*

As shown in Figure 4, the final construction for the rehabilitation consisted of two parts. In part I, a 150m long, 12m high, pile-supported reinforced concrete waterfront protection wall was built for the lower part of the slope below the highest water level (Figure 4a). The piles were installed with a diameter of 120cm and a minimum embedded length of 10m. A total of 115 piles, each spaced 2m, were installed in two rows with all-casing drilling technology and seated into the bedrock for at least 2m. The durable RC structure was used to prevent the instability from river scouring.

In part II, a wrap-around reinforced soil slope containing geogrid, geobag, and geotextile drainage materials were chosen to restore the upper part of the slope (Figure 4b). The benched RSS was constructed with two steps using collapsed spoils piled on-site. Each step has a height of 4 to 6m with an averaged backward inclined ratio of 1:2 (H: V) so that a sufficient width of the highway can be maintained. Considering the safety and the cost, the lower part of the RSS applied stronger geogrid (Type A) as the reinforcing material for a total surface area of 1,326m^2. Another 995m^2 of Type B geogrid with lesser strength was used for the upper part of the RSS. Each layer of the fill material was installed with a vertical spacing of 50cm.

To prevent the surface overflow washing and softening the RSS, a 2m×2m approximately, drainage culvert was installed below the pavement to collect all the possible surface run-off and discharged it directly to the river. Stacked soil-filled geobags were used for slope face protection. It also functioned as the medium of planting as vegetated slope was not only good for an aesthetic appearance but also for an eco-friendly environment.

(a) Construction of pile-supported protection wall. (b) Construction of reinforced earth slope.

Figure 4. Slope rehabilitation under construction.

3 MANAGEMENT OF CARBON EMISSIONS

Carbon footprint is the sum of all emissions of CO_2 which were induced by the development activities of a facility in a given time frame. Usually a carbon footprint is calculated for the time period of a year. It can be calculated as shown in Eq. (1).

$$\text{Carbon Footprint} = \Sigma \text{Activities} \times \text{Emission Factor} \tag{1}$$

Zahra et al. (2015) reported that the carbon footprint associated with the life cycle of a facility and conveyance type can be conceptualized as four components: (1) embodied carbon, defined as the CO_2 emissions associated with extraction and processing of the materials used in construction; (2) carbon emissions incurred during construction and (3) maintenance operations; and (4) sequestration of atmospheric CO_2 in vegetation biomass and soils through photosynthesis (Figure 5).The net carbon footprint was calculated as the summation of carbon emissions associated with each of these components as Eq. (2). Maintenance emissions and carbon sequestration were considered on an annual basis and are thus multiplied by time (in years) to calculate the net carbon footprint for a desired time period.

$$\text{Net Carbon Footprint} = \text{Embodied} + \text{Construction} + (\text{Maintenance} - \text{Sequestration}) \times \text{time} \tag{2}$$

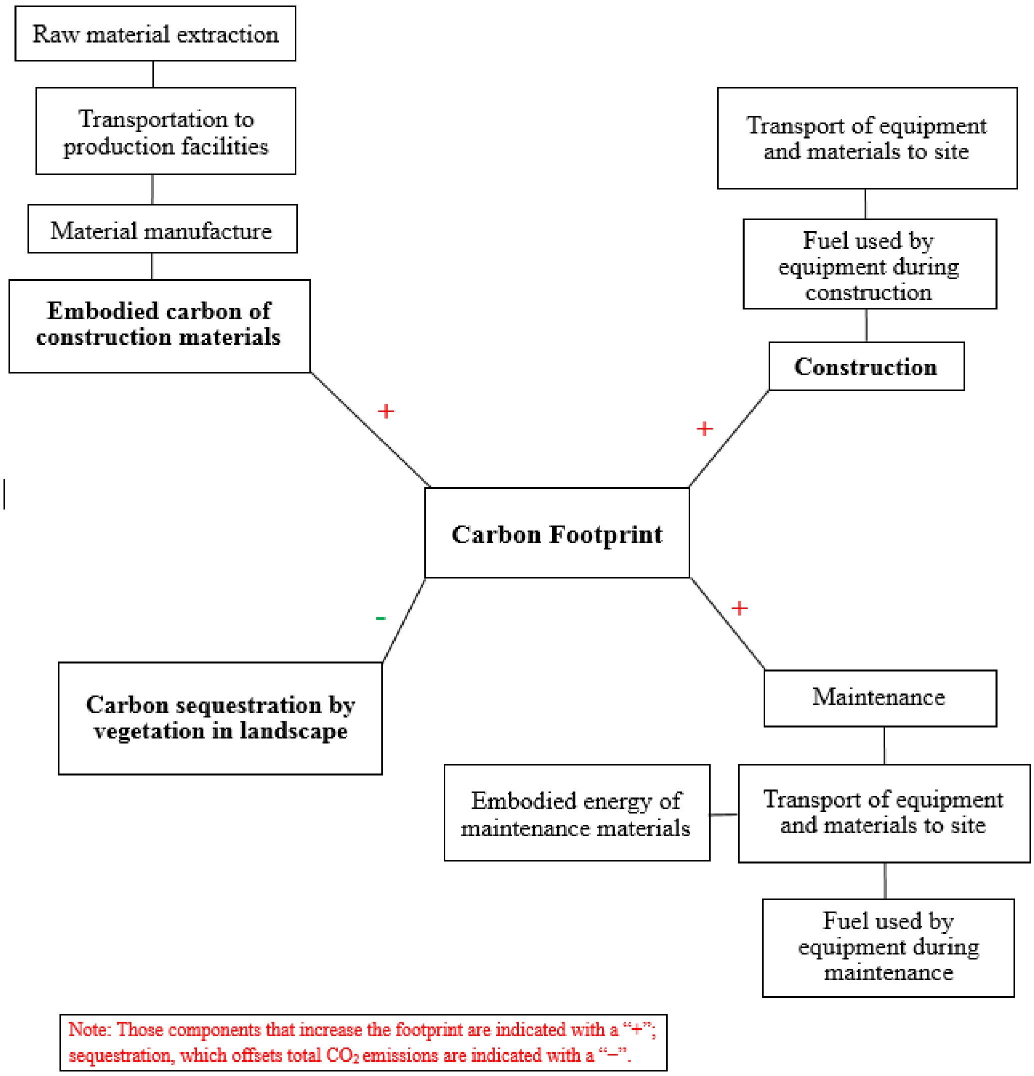


Figure 5. Conceptual model of life cycle carbon footprint analysis for a facility (Zahra et al. 2015).

Because sustainability also was one of the primary missions of this project, this paper highlights the beneficial of carbon footprint of RSS when compared to the traditional retaining structure. However, comparisons made herein only for construction due to the limitation of the paper. Construction emissions included both transportation of construction materials and equipment to the site and emissions by construction equipment during operation. Table 1 shows the estimated carbon footprint associated with the entire rehabilitation for the damaged slope. Total carbon footprint was reported to be 4,905,412 kg-CO_{2e}. Calculations along with estimations of emission factors and carbon accounting were based on Taiwan government official guideline for all relevant items of the construction. Detailed information and calculations are presented elsewhere (PCC 2012, Chen et al. 2017).

As can be seen in Table 1, piles and RC waterfront protection wall contributed as much as about 87% of the total carbon footprint of the construction whereas RSS only presented minor amount of emissions (14.19%). Piles and retaining structure are made of reinforced concrete materials which consume large amount of energy during their production. Table 2 shows the breakdown of carbon emissions calculated for RSS installed in this project. RSS consists of non-metallic geosynthetic material such as polyethylene (PE), polypropylene (PP) or polyester (PET) which need much lower energy consumption when compared to those for cement products. The carbon emissions incurred during extraction, production and processing of construction materials constitute a significant proportion of the total life cycle carbon of the structure. Although concrete structures presented worse result for carbon emission, they were mandatory to assure a safety slope. It can be concluded that the use of RSS not only exhibited competent stability but also demonstrated valuable contribution on the reduction of carbon emission and positively made this project attractive for sustainability. The results presented highlight the importance of considering the life cycle carbon footprint in the engineering design process.

Table 1. Summary of the carbon footprint for all components in the Construction (Chen et al. 2017)

Type of Structure	Carbon footprint (kg-CO_2-e)	Proportion (%)
Pile	1,103,614	22.50
RC waterfront protection wall	3,167,480	64.57
Reinforced soil slope	696,516	14.19
Slope vegetation	-62,198	-1.26
Total	4,905,412	100.00

Table 2. Calculation of the carbon footprint for RSS (Chen et al. 2017)

Component of construction	Unit	Quantity	Emission factor	Carbon footprint (kg-CO_2-e)
Excavation	m^3	26,120	2.51	65,561
Backfill	m^3	26,120	0.74	19,239
On-site transportation (5~10km Distance)	m^3	26,120	7.53	196,684
Rebar construction	kg	1,993	0.74	1,475
Type A RSS	m^2	1,098	231.24	253,902
Type B RSS	m^2	718	127.51	91,552
Type A RSS lateral wrap up	m^2	228	89.14	20,324
Type B RSS lateral wrap up	m^2	277	65.15	18,046
Horizontal intercept drain	m	237	118.07	27,982
2.6mmφ mesh for surface vegetation	m^2	284	5.85	1,661
Total				696,516

4. PERFORMANCE AND EVALUATION

After four months of construction, this project was successfully completed in May 2014. Since then it has been through a number of typhoons attacks and by far still remaining in good condition (Figure 6). Although it has always experienced heavy traffic, no evidence has been observed for deterioration or instability. Vegetated slope presents natural appearance and provides an aesthetic and eco-friendly environment for the site. As many other similar projects already in use, the rehabilitation has been proved successful.

Taiwan is world-famous in its natural scenery but it also has experienced numerous record-breaking natural disasters. For such a beautiful but vulnerable environment, man-made structures should be built as much as possible to satisfy the requirements of durable, aesthetic, sustainable, eco-friendly, and seismic-resistant. The project reported herein proved RSS system to be the novel solution to totally meet the demand of the country.

(a) End of construction. (b) One year after the completion.

Figure 6. Completion of the rehabilitation.

5. CONCLUSION

This paper reports a case study to use a novel solution to restore a damaged downslope. Because sustainability was an important concern of this project, the designer proposed an alternative, with equivalent safety, other than the traditional concrete retaining structure. In addition to the geotechnical analysis, carbon footprint also has been calculated and evaluated for all components of the construction. The rehabilitation consists of a piled-supported reinforced concrete protection wall and a reinforced slope with geosynthetics. Such approach is not common; however, the experience described herein has shown that the reported composite retaining structure meets all the site criteria. The results also highlight the beneficial of carbon footprint of RSS when compared to the traditional retaining structure. However, despite concrete piled-structures presented worse result for carbon emission, they were durable to prevent the toe of the slope from scouring. The completed rehabilitation successfully stabilized the slope and assure the safety of the highway. Furthermore, it made a vegetated terrain that has presented a natural appearance and provided an aesthetic and eco-friendly environment for the site.

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