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Designing vertical and horizontal frame structure for slope protection

Md. Toriqul Islam[1], Md. Zakaria Hossain[2], Masaaki Ishida[1]

[1]Department of Sustainable Social Systems, Mie University, Japan
[2]Department of Environmental Sci. and Tech., Mie University, Japan

***Corresponding author: zakaria@bio.mie-u.ac.jp**

Abstract

Composite frame structure, a reinforced cementitious composite, attains its optimal reinforcing capability for land reinforcement applications owing to its synergetic action from two components of wire mesh and mortar. This paper presents some field performance on the composite technology for vertical and horizontal frame structures reinforced with woven square mesh. Design and fabrication of composite technology for land slope protection are depicted in this paper that can be applied in Japan and other countries of the world. The selected structures that have been identified for land slope protection are skeletal frame of soil anchoring, land reinforcements, hill cover and slope surface lining. Design sketches of various composites along with fabrication procedure are depicted. Some examples of practical applications of this composite technology have been demonstrated using simple techniques. Based on the cost of required materials and labor, the cost of fabrication per unit area of composite structure has been calculated. It is concluded that the required cost of the composite frame structure was US$ 60 per square meter. New concept depicted in this paper is applicable for the construction of strong, durable and cost-effective frame structures for land slope protection.

Keywords: Composite structure, Design, Fabrication, Slope protection, Application.
Abbreviations: JIS_Japanese Industrial Standard, N_Newton, mm_Millimeters, b_Distance between frames.

Introduction

It is well known that conventional reinforcements used for reinforcing land, contain only one type of material such as geogrid, geosynthetic or wire mesh. Generally, the material used in soil reinforcement applications must be safe against tension failure and adhesion failure for its effective utilization in the field and reliable design of land. A single type of material can provide limited reinforcement capability in reinforced land structures due to its low frictional resistance and poor cohesion. For an optimal response, therefore, different types of reinforcement, that fulfills both requirements such as possess adequate tensile strength and frictional resistance, are getting considerable attention lately (Hossain, 2010). Composite frame structure, a reinforced-mortar composite consisting of evenly distributed fine wire mesh as the reinforcement and cement-sand mortar as the matrix can be a prospective complimentary material for this perspective. The enhanced performance of composite frame structure over conventional reinforcement comes from its synergetic action of mesh with mortar and mortar with land. In composite frame structure, high tensile steel wire mesh provides adequate tensile and pullout resistance, while the sand-cement mortar provides adequate frictional resistance and improved cohesion owing to its relatively greater surface area and roughness as compared to conventional land reinforcing materials. If properly designed, the rough surface of composite frame structure can grip the soil particles, and the frictional resistance needed for optimal design against failure can be significantly improved. Composite technology consists of sand-cement mortar reinforced with wire mesh are used in the construction of various structures (Naaman, 2000) It has also been used for making linings to bridge arches, swimming pools, flumes, aqueducts, thin shell structures and low-cost farm structures (Awal, 1987; Hossain and Inagaki, 2011) . Research and development work on this material in Japan, however, are not so many (Hossain and Hasegawa, 1997). According to Hossain and Inoue, 2000; Hossain and Sakai, 2006, only a few research institutions in Japan like Building Research Institute, Tokyo Institute of Technology, Nihon University including the Mie University and Kyoto University have applied the composite techniques. However, these are mostly limited to demonstration only (Ohama and Shirai, 1984; Shirai and Ohama, 1984). In view of the above distinct advantages of this material, it may be effective to utilize this technology for land slope protection in the hilly country like Japan and other countries of the world. Understanding the facts stated above, a study was undertaken in Mie University, Japan with the following objectives. (1) to identify the structures that can be made with composite technology for land slope protection, and (2) to present the fabrication process and cost estimation of composite structures for land slope protection.

Results and discussion

Composite thin structures

The sketches of various composite structures identified for slope surface protection are given in Figs.1-8. Based on the cost of the materials and labors, the cost of construction of composite for slope surface protection has been estimated and given in Table 1. The shape the edge of a composite structure used for land slope protection is shown in Fig.1. Both the upper and lower edges have vertical portions (flanges) of 30 cm or more depending on the field conditions. Due to these two vertical portions of flanges, the edge of composite structures

Table 1. Calculation of the cost of composite structure for land slope protection

Items	Cost (Yen)	Cost (US$)
Price of mortar per cubic meter (cement:sand=1:4)	15200.0	126.67
Mortar per square meter with thickness 7 cm, (1 cubic meter×0.7)	1064.0	8.87
Wire mesh (dia.2mm, cc opening 50mm) per square meter	230.0	1.92
Anchor pin and spacer, tools etc. per square meter	206.0	1.72
Mortar mixing, spraying, labors etc. per square meter	3000.0	25.00
Total cost composite structure per square meter	4500.0	37.5

Note: 1US$=￥75 (4500yen=60US$), Sept.01, 2011

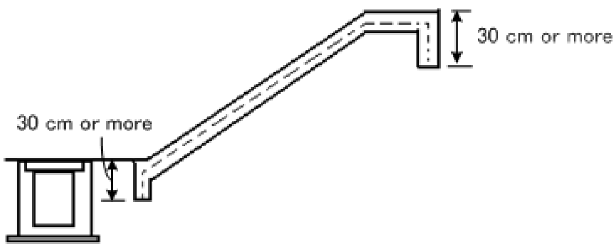

Fig 1. Shape of the edge of composite for slope protection.

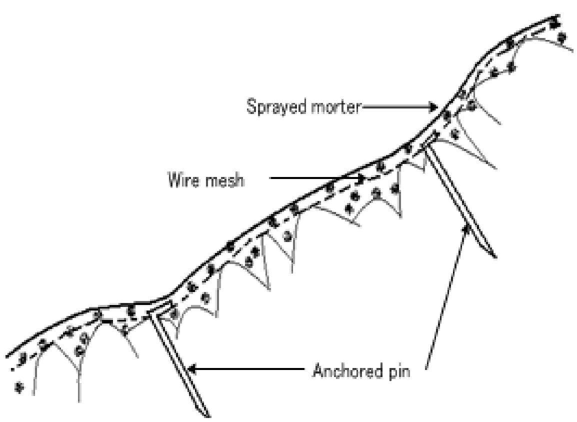

Fig 2. Cross-sectional view of composite and the anchored pin used for slope protection work.

would be fixed on the slope and prevent water entry just underneath the composite layer. According to the needs, however, one can make the structure without any flanges or the flanges can be made of variable sizes. A cross-sectional view of the composite structure with mortar, mesh and the anchored pin is shown in Fig.2. The length of the anchored pin ranges from 200 to 400 mm with diameter of 13 to 16 mm depending on the slope conditions and position of the pin. The anchored pin is used to hold the mesh on the surface of land slope during construction and to facilitate the composite structures to be fixed on the slope during on-service. The average thickness of the composite structures used for slope protection is usually 6 to 7 mm. However, this can be little bit thicker due to the unevenness of the surface of the slope. A part of the completed composite structures for slope surface protection is shown in Fig.3. This figure also shows a portion of the mesh and the application technique of the mortar on the mesh.

Composite frame structures (vertical)

Another item of composite that has been made for use in slope surface protection is the composite frame structures (Figs.4-8). Traditional structures made of brick are neither strong nor suitable for mass use in slope protection works. Concrete made frame structures are found to be expensive and intricacy in construction. Because of high adaptability of composite to various structural forms and ease in construction and economy; the composite technology can be applied in making not only the complete layer on whole surface of the slope as shown in Fig.3 but also be employed in constructing frame structures especially for large scale slope or the like. The sketches of composite frame structure having joint at the vertical column is shown in Fig.4 and the corresponding completed structure having joint in vertical frame is shown in Fig.5. For the case of the joint in vertical frame, the joint is usually made at a distance of *b*/2 from the nearest frame that has ground anchor and the next ground anchor is made at a distance of *b* between the two frames (Fig.4).

Composite frame structures (horizontal)

On the other hand, for the joint in horizontal frame, it is usually made at the mid-section of the frame with the distance *b*/2 from the center of the nearest frame as shown in Fig.6. In this case; usually, the ground anchor is provided at all intersectional points of the frame (Fig.6). The corresponding completed structure having joint in horizontal frame is shown in Fig.7. This technique of composite structure for land slope protection allows greeneries between the frames, and thus conserves the environment. Therefore, the composite technology for the land slope protection can be treated as the environmentally friendly technology and the composite can be termed as environmentally friendly material, especially when dealing with the land slope. The design of the horizontal and vertical frames along with the placement of mesh, skeletal steel and ground anchor is shown in Fig.8. Usually, the placement of skeletal steel and the mesh in the vertical frame is done firstly then the placement of skeletal steel and the mesh in the horizontal frame is performed. As can be seen in this figure that the mesh of the vertical frame is cut at the mid-section of the two horizontal meshes and then bent it outside. This facilitates the ease of placement of mortar and the aesthetics of the structures. The ground anchor is provided at the position close to the skeletal steel instead of the center of the intersection in order to clamp and hook the frame to be remained in its position during casting and on-service. The cost of different items used for the construction of composite structures for land slope protection is summarized in Table 1. The cost given in Table 1 is calculated based on the costs of materials and labors. Though it has not been the prime objective of the studies to compare the cost of composite structures with other varieties of materials, it can, however, be emphasized that the composite structures are relatively cheaper than those made with traditional materials like timber, steel and such other materials.

Discussion

In the field of land slope protection, the basic materials needed for composite constructions are wire mesh, sand, cement and

Fig 3. A part of completed composite for slope protection (Sasagatake mountain, Iga city, Mie).

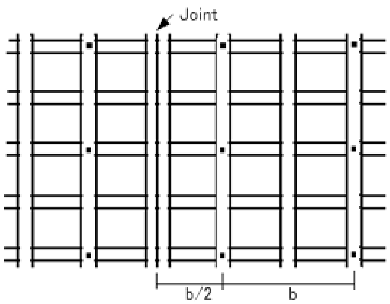

Fig 4. Sketches of composite frame with vertical joint for slope protection.

Fig5. Completed composite frame with vertical joint for slope protection (Sasagatake mountain, Iga city, Mie).

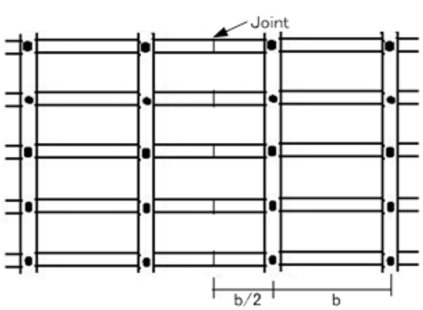

Fig 6. Sketches of composite with horizontal joints for land slope protection.

water. The skeletal steel is used in the construction of composite frame structures for land slope protection. Discussion about the constituent materials and construction procedure is given below.

Wire mesh

As given above, there were different types of meshes used in composite works. It is one of the most essential components of composite especially for slope surface protection works. The wire meshes must be easily handled and flexible enough to be bent around sharp corners and unevenness of the slope surface. The main function of the wire mesh in slope surface protection is to act as a lath providing the form and to support the mortar during the hardened state of composite. The wire meshes absorb the tensile stresses on the structure which the mortar, on its own, would not be able to withstand. In this project, special types of steel wire mesh (galvanized metal mesh) having 2.0 mm wire diameter with c/c spacing of 50 mm was used. The mesh (Fig.9) has been folded for the ease of transportation and can easily be spread during construction. It has been coated with zinc to protect from rusting according to the Japan Industrial Standard (JIS G3552).

Cement

The ordinary Portland cement is the most commonly used in Japan among several types of cement available commercially. In the present study, the ordinary Portland cement (JIS R5210) was used throughout the research work. This type of cement is adequate for application in land slope protection

Sand

For composite work, well graded coarse sand is commonly used. In the present study, the river coarse silica sand is used. The sand is passing through 5.0 mm sieve and the fineness modulus of it was 2.5.

Water

Water plays a vital role on the resulting hardened state of composite. Sea water or water with any impurities such as acids, soluble salts and any organic matters are not at all suitable for mixing mortar as they may increase the risk of corrosion or interfere the setting time of cement and finally the strength of the composite. In this study, tap water was used for making the cement mortar.

Construction procedure

Placement of wire mesh

For placement of wire mesh, no skeletal steel frame is needed for the composite work in land slope protection. The slope was cleaned after removing the trees, grass and any other element before placing the mesh. An example of this procedure is shown in Fig.10. Following the shape of the slope surface, one layer of wire mesh was placed on the slope that was spread from the top of the slope to the bottom. The mesh was tied with the slope by hooks called as anchored pins. The most common size of the anchored pin was 13-16 mm in diameter and 20-400 mm in length depending on the position slope. The placement procedure of the wire mesh is shown in Fig.11. The anchored pin used for fixing the wire mesh on the slope is shown in Fig.12.

Fig 7. Completed composite frame with horizontal joints for land slope protection (Sasagatake mountain, Iga city, Mie).

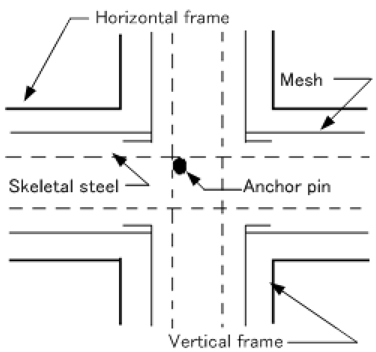

Fig. 8 Method of processing the intersection point of the composite frame.

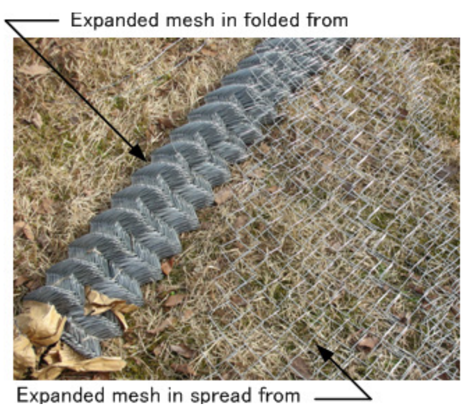

Fig 9. Mesh used for composite technology for slope protection.

Fig 10. Cutting of trees and cleaning of the slope before pacing the mesh (Sasagatake mountain, Iga city, Mie).

Fig 11. Placement of wire mesh on the slope surface (Sasagatake mountain, Iga city, Mie).

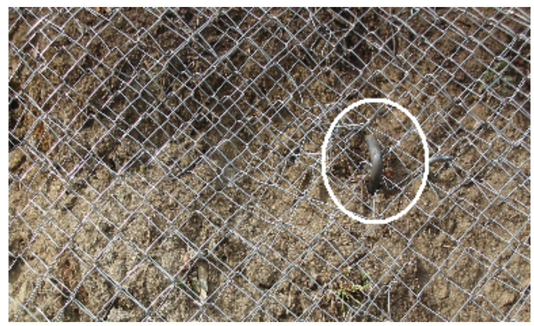

Fig 12. Anchored pin for fixing the mesh on the slope.

Preparation of mortar

In order to obtain the desire strength of the structures, it is very important to select the suitable proportion of the cement to sand ratio. For the composite in building works, the proportion of cement to sand generally varies from 1 part of cement to 1.5 or 2 parts of sand by weight. However, for the composite in slope protection works, the proportion of cement to sand was taken as 1 part of cement to 4 parts of sand by weight. This provided the strength of composite more than 15 N/mm^2 which was considered enough for slope protection works. The water to cement ratio was 0.45. However, it can be varied depending upon the dryness of sand. In the mixing process, the sand and cement were mixed uniformly. The water was added gradually part by part in order to obtain the required workability on the mortar mix.

Plastering

The plastering technique employed in this study was done by spraying the mortar by a particular form of pressurized gun which is supplied with compressed air. The apparatus consisted of a pump and an air compressor which enabled spray applications. The application was controlled remotely from the mortar supply for the in-situ composite of slope surface. The spray pattern of the pressurized gun was adjustable. Controlling the mortar supply and air pressure helped to reduce the problems associated with excessive spray formation and rebound of the applied mortar. The mortar was normally remained in position after placing due to stiff mixes.

Curing

The objective of curing was to keep the mortar saturated and to promote the hydration of cement. There were several methods of curing. In this research, the moist curing was followed for about one week. Finally, the composite structure was cured for long time with the moisture of the land.

Conclusion

Composite frame structures have been identified and constructed in this research study are some of the examples that can be constructed for land slope protection using composite technology. Results obtained have demonstrated that the utility and economy can both be achieved using very simple techniques utilizing locally available materials. It is expected that the observations made in this study will bring the new concept in gaining wide acceptance of composite for the construction of strong, durable and cost-effective composite frame structures for land slope protection.

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