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Application design of concrete canvas (CC) in soil reinforced structure

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A B S T R A C T

Concrete canvas (CC for short), which is a flexible cement powder impregnated fabric that hardens on hydration to form a thin, durable water proof and fire-resistant concrete layer, has been used in slope protection, and CC may also have widely potential application in retaining wall structure. This article presents the design methodology for the CC-faced reinforced soil retaining wall structure according to the mechanical properties of CC. The result demonstrates that carbon nanotube (CNT) modified ultra-high molecular weight polyethylene (UHMWPE) unidirectional fabric reinforced CC can be applied to the reinforced soil retaining wall with a height of between 3 m and 10 m, and reasonable spacing of reinforcements is 0.5 ~ 1 m. In addition, the connection between the reinforcement and CC wall can be safely against bearing capacity failure. Finally, the results of a FEM parametric study indicate that the horizontal displacement of CC is a little large (about 20 mm @ 6 m height retaining wall). Relative large maximum displacement of the CC wall indicates that the high stiffness reinforcement should be used to reduce the overall horizontal displacement of the wall.

1. Introduction

In modern slope protection and retaining wall projects, many complicated construction environments may be encountered, sometimes repair projects may also need rapid construction. In addition, the difficulty of construction further increases due to the short construction period, the irregular face shape of soil and rock mass, etc. Conventional materials and construction methods will meet trouble in extreme environmental conditions. So the new types of materials and novel construction technologies need to be developed to fit the critical requirement in various situations.

Textile reinforced concrete (TRC) has various advantages such as high tensile strength, excellent ductility, light-weight, thinner thickness and resistance to corrosion (Hegger and Voss, 2008; Colombo et al., 2013). As the reinforcement component, textile can improve the tensile strength significantly. Besides the fiber type, geometry of textile, including weft yarns spacing and stitches size (Peled et al., 2008; Peled, 2011), the bundle size of yarns (Hartig et al., 2008) may also significantly affect the reinforcing efficiency.

Due to the capability of reinforcing the matrix in three directions, 3D spacer fabric presents superior performance and becomes a more attractive product when applied to the TRC system (Armakan and Roye, 2009). Therefore, 3D spacer fabric has widely potential application in civil engineering. Amongst, concrete canvas, which was invented by Brewin and Crawford in 2005 in UK, is one of the most promising products (Concrete Canvas Ltd).

Concrete canvas (CC for short), is a flexible cement powder impregnated 3D spacer fabric that hardens when hydrated to form a thin, durable and water proof and fire-resistant concrete layer. The properties of the components, including cement matrix, type of fiber, and geometric pattern of fabric directly affect mechanical strength and volume stability of CC (Bao, 2013; Han et al., 2014, 2015a, 2015b). Normally CC is cloth-like rolled up (as shown in Fig. 1) and sealed in the package by the manufacturer, then it can be transported to the project field for using easily. CC allows construction without the need of mixing/casting/finishing equipment and framework. Engineer simply positions CC on the surface of the target and just sprays water. Compared with the traditional

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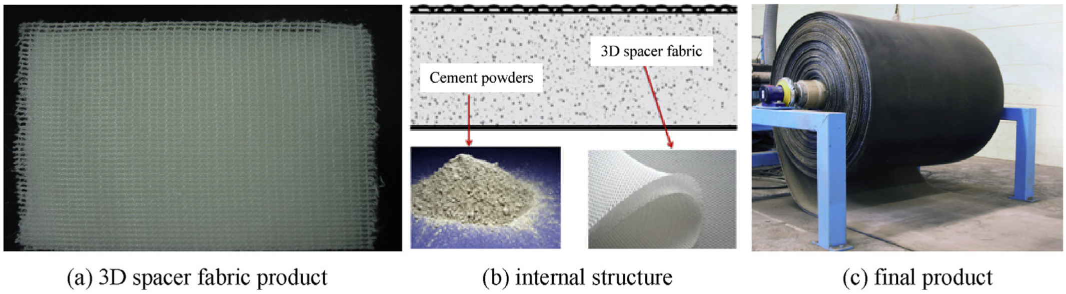

Fig. 1. A typical 3D spacer fabric and compositions of concrete canvas.

concrete solutions, CC is a faster, easier and more cost-effective product to install and has the excellent benefits of reducing the environmental impact, shortening construction period and lowering labor cost. Obviously, CC material, if applicable, could result in cost effective retaining wall construction.

Finite element modeling technique was previously employed to analyze retaining wall structure (e.g. Hussein and Meguid, 2016), and the reliability of the simulation results was proved by comparison with the experiment results (Athanasopoulos-Zekkos et al., 2013). It can provide designers with immediate feedback on structural performance when principle decisions related to the form are being made, and the results obtained with the finite element method (FEM) provide more detail than other method.

CC has been increasingly used to slope protection (as shown in Fig. 2), and it may be an ideal material used as the wall face of retaining wall structure. However, there is no actual project case of utilizing CC as the facing wall of the retaining wall structure worldwide, and the relevant design principle of CC in the application of retaining wall was not addressed yet in the literature. In this study, CC sample is prepared, its basic mechanical properties are investigated, and the preparation process is improved in order to increase its flexural strength. Then a brief construction procedure of CC-faced retaining wall is presented, and the initial design is presented which includes the shear stress calculation, the thickness design of the retaining wall and reinforcement distance design. Finally, the results are verified via FEM, and the horizontal displacement of retaining wall is also calculated via finite element analysis.

2. Materials and mechanical properties of CC

As indicated in Fig. 1 (b), CC is composed of a 3D spacer fabric and cement powder filled in-between. The mechanical properties of CC closely depend on the raw materials as well as fabrication process.

2.1. Raw materials

2.1.1. 3D spacer fabric

The 3D spacer fabric plays an important role of offering a space for the cement powder filling and enhances the tensile strength of the composite. Normally, the thickness of 3D spacer fabric is about 8–20 mm, and the maximum thickness dependent on the type of the woving machines can reach 60 mm (Karl Mayer GmbH, 2014). In this study, the fabric is produced on a double needle bar Rachel warp knitting machine GE2298 from Wuyang Textile Machinery Co. Ltd. The detail characteristics of fabric are illustrated in Fig. 3. It can be seen from Fig. 3 that the surface layer of 3D spacer fabric consists of two types of fabrics: one is mesh fabric (MF), the other is solid fabric (SF); in between is spacer yarns, all the fibers used to weave the MF, SF and spacer yarns are made of polyethylene terephthalate (PET) filaments. As shown in Fig. 3, since the fabric density of SF is much higher than that of MF, the dry cement powder can easily pour into the 3D space fabric from the gap of the MF, and fill the space between the spacer yarns via vibration. The SF can prevent the cement powder from leaking through the bottom layers of the 3D space fabric. Once the mesh fabric is coated with PVC membrane, the cement powder is sealed inside the 3D spacer fabric without leakage. Obviously, the mechanical performance of the 3D spacer fabric depends on its structure. The fabric used in this study is warp knitted fabric, and there are three characteristic directions: warp, weft, and through-the-thickness directions. The warp yarns in the warp direction are inserted into the stitches and assembled together with the weft yarns in the weft direction, and then a grid net is produced and the meshes in the net are knitted in rectangle shapes. Additionally, oriented spacer yarns are inserted into the structure to the amount of $70/cm^2$. All warp/weft yarns between the two layers of 3D spacer fabrics are in twisted form. The yarns between the layers can enhance the adhesive strength between the fabric and the cement powders. The yarns' physical properties of the 3D spacer fabric, as determined by a yarn tensile tester with 30 N capacity (XL-2) from Shanghai New Fiber Instrument Co. Ltd., are summarized in Table 1.

Fig. 2. Concrete Canvas is rolled off a crane to stabilize a slope (Photo courtesy of Concrete Canvas Ltd.).