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Field Investigation on Wall Facing Deformation of Mechanically Stabilized Earth (MSE) Walls Constructed using Cement Modified Marginal Soil with Built-In Facing

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Abstract: **It appears that the reasonable way of providing a realistic approach for Mechanically Stabilized Earth (MSE) walls is to construct model walls in the field and study their performance at failure. Hence, it was decided to study the behaviour of model MSE walls constructed using conventional (standard) backfill and marginal soils. This study was undertaken to investigate the mechanism, qualitative behaviour and potential benefits of using cement modified marginal backfill soils under cyclic loading.**

A field study was undertaken to evaluate the performance of model non–woven geotextile reinforced MSE walls constructed using locally available marginal backfill soils without and with cement modification. In the present study, an attempt was made to make a built–in soil cement facing out of same backfill soil with extended reinforcement into it, which is folded back within the lift thickness. As this type of built–in facing that does not involve the connection problems and tried as an alternative to conventional facing panels. The facing deformations were measured using dial gauges during load testing. The load testing was continued until failure of the respective walls was reached.

Key Words— **Mechanically Stabilized Earth; Marginal soils; Geotextile; Wall Deformations.**

I. INTRODUCTION

Henri Vidal, a French Engineer, in the year 1969, developed the modern form of reinforced soil technique, a method of retaining earthen material by the incorporation of reinforcing elements in the form of metal strips at regular intervals in a frictional granular material in the longitudinal direction and covering with facing elements, thus forming a new composite and coherent material (Hausmann, 1990; Biswas et al. 2003; Goel, 2006). In addition, different materials such as steel bars, wire mats and geosynthetics have been used as reinforcements for this system (Leshchinsky and Han, 2004). The general form 'Reinforced Soil' or 'Mechanically Stabilized Earth (MSE)' is used in place of 'Reinforced Earth'. The usage of MSE walls has increased rapidly during the past four decades as the technology is simple, reliable, rapid, versatile, cost effective and performance advantageous compared to conventional retaining walls (Hausmann, 1990; Chen et al. 1996; Leshchinsky and Han, 2004). Moreover, these structures are essentially flexible structures that can generally accommodate large lateral and vertical movements without excessive structural distress (Chen et al. 2007).

Despite the wide appreciation of the technique for its versatility, in the recent years, few problems and failures of reinforced soil structures were reported (Yoo et al. 2004; Sahadat and Victor, 2007). The reasons for their failure were attributed to the use of inappropriate backfill materials, difficulty in facing connections and sometimes, poor compaction control and displacement of facing panels (Suah and Goodings, 2001; Zimmie et al. 2005). The difficulty in erection of facing and its connection to reinforcement, and also a few connection failures of MSE walls were reported by other investigators (Collin, 2001; Goel, 2006).

On the other hand, the non–availability of conventional frictional granular backfill soils at many work sites, lead to a growing interest in the use of marginal backfills (cohesive soils with a large percentage of fines) for the construction of MSE structures and a limited research had been done relevant to the usage of marginal backfill soils. It is felt that the economic advantage of MSE walls will markedly increased if on–site marginal soils are used as the backfill material (Glendinning et al. 2005; Farsakh et al. 2006). It was also felt that the use of marginal soils as backfill in reinforced soil construction could be recommended if comprehensive internal drainage could be provided (Zimmie et al. 2005;

Goel, 2006). Further, it was opined that cohesive–frictional soils could be a convenient compromise between the technical benefits of cohesionless soils and economic advantages of cohesive soils (Keller 1995; Saran 2006). Other techniques such as the use of electrokinetic geosynthetics to aid drainage in cohesive backfills (Glendinning et al. 2005; Fourie et al. 2007) and preloading and prestressing (Tatsuoka, 2002) to make reinforced backfill very stiff and elastic were suggested in the recent years. However, these techniques involve stringent quality control and technical difficulties, especially with large–scale works. It was also felt by some researchers (Tatsuoka, 2002; Mohammad and Mohammad, 2006) that the cementitious modification of backfill materials could offer a promising lasting performance of reinforced soil structures.

The present paper deals with the use of marginal backfill soil without and with cement modification in the construction of model MSE walls and the feasibility of using an alternative method of constructing built–in soil cement facing with folded back geotextile layers was also investigated with a view to overcome the erection and connection problems of conventional types of facing. The performance of built–in soil cement facing adopted in the construction of model walls investigated by measuring the facing deformations during load testing.

Materials Used for Experimental Analysis Conventional Backfill: Sand

Sand classified under SP (poorly graded sand) was used as reference material to compare the performance of cement modified upland marginal soil. Gravel (5%), Sand (95%); Non Plastic; Unified soil classification (SP); Optimum moisture content (12%); maximum dry density (1.58), Shear strength parameters: CD condition c' (0 kPa), ϕ' (410); Coefficient of permeability, k (1.25 × 10 –3cm/sec).

Marginal Backfill Soil

Locally available soil was used to simulate the marginal backfill soil. Gravel (0%); Sand (58%); Silt (24%); Clay (18%); Liquid limit, w_l (39%); Plastic limit, w_p (17%); Unified soil classification (SC); Optimum moisture content (16.5%); maximum dry density (1.78); Shear strength parameters: UU condition c_u (52kPa); $\phi_u(14^0)$; CD condition c' (0 kPa); ϕ' (41^0); Coefficient of permeability, k (2.48×10^{-6}cm/sec).

Cement

Ordinary Portland cement of 53 grade was used to modify the marginal backfill soils and also to form the built–in soil cement facing of model MSE walls.

Soil–Cement

The cement modification was adopted to overcome the ill–effects of fines and their plasticity on the performance of these walls. With the small quantities of cement generally used, soil–cement functions essentially as a soil, although it is an improved one. In order to overcome ill effects of fines and their plasticity of marginal backfill soils, cement modification was adopted. Though these soils have become non–plastic with 2% cement content, 3% cement content was used to account for the possible non–uniform mixing of cement while handling considerable quantities of backfill materials used in this investigation.

Reinforcement

In this study, non–woven geotextile (Fibertex G–100) was used as reinforcement in this investigation and its properties as supplied by the manufacturer are: Weight = 100 g/m^2; Thickness at 2 kPa = 0.6 mm; Static puncture (CBR–test) resistance = 940 N; Elongation = 55%; Tensile strength in longitudinal direction = 4.0 kN/m; Tensile strength in transverse direction = 5.0 kN/m; Elongation at break = 40–50%; Dynamic cone drop resistance = 40 mm; Permeability = 0.13 m/sec; Permittivity = 2.6 Sec^{-1}; Water flow = 130 l/sec/m^2; K_{darcy} at 2 kPa = 10 × 10^{-4} m/s; Pore size, $O_{90\%}$ = 110 micron.

Construction of Model MSE Walls and Field Investigation

Model MSE walls of 2.50 m wide and 2.40 m high were constructed using Fibertex G–100, non–woven geotextile reinforcement at 0.30 m vertical spacing with folded backs at the facing. In order to form the vertical facing of these model MSE walls, four specially fabricated steel form shutters of 0.40 m high and 1.00 m long were used to have smooth and uniform face finishing. These form shutters, two on either side were placed at 2.50 m apart and the appropriate size of Fibertex G–100, a non–woven geotextile layer (first layer) was spread without any creases on the leveled compacted surface of the ground (Plate 1). Steel form shutters were given a slight batter or tilt towards backfill in order to compensate the outward movement during placement and compaction of backfill. This movement tended to push the steel form shutters to a true vertical position. For each layer, plumb line method was used to ascertain the verticality and alignment with respect to lower layers in order to assure a uniform vertical built–in soil cement wall formation. The respective fill material of 5 cm thick was placed manually over the geotextile layer, flattened by the grader and compacted using a 2 ton stone roller at its optimum moisture content. In order to form a 300 mm thick built–in soil cement facing, the same backfill soil was mixed with 10% cement content and compacted near the facing simultaneously with the placement of respective backfill (Plate 1).

After placing and compacting the backfill material, the anchoring length of geotextile is wrapped over the compacted fill within each lift thickness as shown in Plate 1. Further, placement of backfill and the formation of facing were continued up to the top of first lift and then the next layer of geotextile was placed over the compacted soil layer and the procedure was repeated until the construction of model MSE wall of required height was completed.

MSE wall with marginal backfill soil without cement modification were constructed for load testing both at optimum moisture content and in fully wet condition respectively. Two more walls were constructed again using marginal soil as backfills after admixing with 3% cement content. In case the wall constructed using sand as backfill, no cement modification was adopted, as it is a non plastic, free draining and frictional material, for which the load testing was carried out only at optimum moisture content.

Plate 1. Wrapping with geotextile layer over the compacted fill within the lift thickness

Built–In Facing

In the present work, a built–in soil cement facing with folded back geotextile layers was proposed in the construction of model MSE walls using conventional backfill (Sand) and locally available marginal backfill soil and they were tested under cyclic loading at different test conditions.

The built–in soil cement facing of 300 mm thickness was made using the same backfill soil mixing with 10% cement content and compacted near the facing simultaneously with the placement of backfill and anchoring length of geotextile layer was wrapped within each lift thickness (Plate 1), thus forming a built–in facing.

Load Testing

After the desired height of 2.40 m was reached, cyclic plate load tests were carried out on all model MSE walls constructed using conventional backfill (Sand) and marginal soil. In case of MSE walls constructed using marginal backfill without cement modification, cyclic plate load tests were conducted both at optimum moisture content and in fully wet condition. For the walls constructed using cement modified backfills, the load testing was done at 7 days curing period by inundating the walls to simulate fully wet condition.

Test Procedure

Load was applied centrally over the top surface of model MSE walls through a 300 mm diameter and 38 mm thick steel plate with the help of a hydraulic jack. A proving ring of 20 ton capacity reacting against the knetledge loading frame (Plate 2) was used to measure the load and two dial gauges of least count of 0.01 mm were set on the steel plate to measure the settlements during load testing.

Plate 2. Observations during cyclic loading and built–in soil cement facing deformation of constructed model MSE wall.

A seating load of 5 kPa was applied initially to ensure proper contact of loading plate over the compacted leveled soil surface of model MSE walls and then dial gauge readings were set to zero. Later, the loading was applied in increments of 25 kPa and each increment was maintained till the settlement was less than 0.01 mm per hour up to the first loading cycle of 100 kPa and then it was unloaded in 50 kPa decrements.

Wall Facing Deformations

The lateral outward deformation of model MSE earth wall facing profile was measured during cyclic load testing with the help of dial gauges of least count of 0.01 mm set against facing by fixing them to a square tubular rod with the help of magnetic base (Plate 2). Care was taken for any slip of the magnetic base, by binding it with the help of mild steel wire to the tubular rod. Small square shaped metallic plates were stuck to the either side wall on which pointers of dial gauges were mounted. Dial gauge readings were observed at different elevations with loading intensity for all test conditions and the lateral deformations corresponding to ultimate loads were plotted. The variations of these facing deformations along the wall height are noted under different test conditions.

Discussion on Wall Facing Deformations

The lateral wall facing deformations at different elevations with loading were recorded for all the test conditions and the plots showing the variation of facing deformations with loading intensity on the footing plate were drawn. A typical such plot for the wall with murrum backfill at an elevation of 1.80 m above ground level is shown in Fig.2.

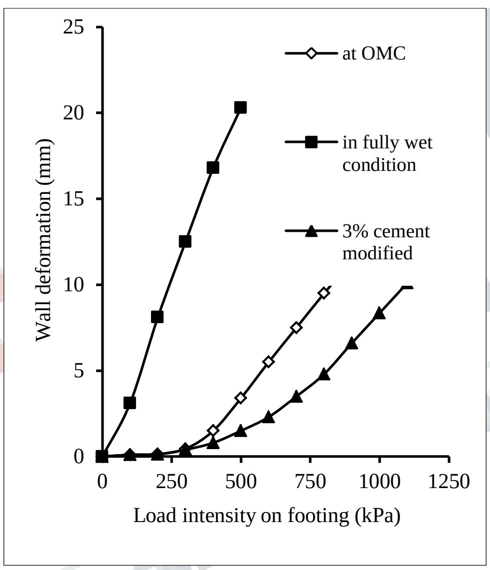

Fig. 2. The variation of lateral facing deformation with loading under different test conditions for constructed MSE wall at 1.80 m above ground level

From these plots, the facing deformations at different wall elevations corresponding to the ultimate loads were obtained for varied test conditions. The variation of these facing deformations along the wall heights is shown in Fig.2.

It can be seen from this figure that the maximum lateral facing deformations in fully wet condition of walls with cement modified marginal backfills are reduced to about one–third of the respective walls with plain backfills, indicating their improved performance. These trends can be supported by the fact that the marginal soils have become unaffected by wetting upon cement modification. The desired aesthetics can also be given to the built–in soil cement facing by plastering the surface accordingly.

CONCLUSIONS

The reduction in load carrying capacity of walls upon wetting of marginal backfills could be compensated by 3% cement modification of such soils. The performance of model MSE walls constructed using cement modified marginal backfills was found to be even superior to the wall constructed using free draining sand backfill in terms of higher load carrying capacity with reduced lateral deformations. It was observed that the geotextile reinforcing layers in marginal backfills facilitated the internal drainage. The performance and utility of the proposed built–in soil cement facing with wrap around geotextile layers was also examined and found to be a potential alternative to conventional facings, as it does not involve the erection and connection problems that could help in faster rate of construction of MSE walls.

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