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Construction and observations of fabric retained soil walls

Construction et remarques sur les murs de soutènement en textiles non tissés

RESUME

Chaque année, de nombreux kilométres de routes secondaires sont construits en terrain montagneux. On a donc besoin d'ouvrages de soutènement bon marché, souples et faciles à construire dans des endroits éloignés. Les murs de soutènement en textile semblent apporter une solution satisfaisante à ce problème.

Les murs de soutènement en textile sont composés d'une alternance de feuilles de textile et de remblais compactés. Chaque feuille est rabattu par-dessus la couche recouvrante de remblai et est maintenu par la feuille superieure afin de retenir le sol, et de prevenir les éboulements. Cet article présente les resultats des études faites sur un modéle, et décrit la conception, la construction ainssi que les performances de deux murs déjà éxistants, dans lesquels le textile utilisé est de type non tissé, aiguilleté et à base de filaments continus.

Les études sur modéle mirent en évidence les possibilités de tels murs, et démontrèrent qu'une légère modification de la théorie Rankinienne de la poussée latérale permettrait d'appliquer cette théorie à de tels murs. Le premier mur existant, haut de 3,3m., démontra les qualités de ce type de construction sur le terrain. Un revêtement de gunite fût appliqué sur ce mur pour le protéger du vandalisme et de l'action des ultra-violets.

Le second mur, construit suivant les mêmes techniques était haut de 6 mètres et se composait à la fois de textiles en polyester et polypropylene. Des méthodes de construction perfectionnées ont été employées et ce mur démontra sa simplicité à édifier et son faible prix de revient. Dans ce cas-ci, le revêtement exterieur était à base d'asphalte, afin de protéger le mur de l'action des ultra-violets. Des mesures précises faites sur ce mur ont montré aprés un an et demi que les déformations sont de faibles amplitudes. Aucun affaissement n'a été enregistré, dans un cas comme dans l'autre.

Les murs de soutènement en textile sont pratiques pour résoudre certains problèmes de mur de soutènement de moyenne dimension, et méritent plus amples developpements et études.

INTRODUCTION

Every year thousands of kilometers of low standard roads are constructed in unstable mountainous terrain. There is a great need for earth retaining structures which are inexpensive and convenient to build at remote sites. Development of a fabric retained soil wall concept shows premise as one solution to this problem.

Fabric retained soil walls are constructed by placing horizontal layers of an appropriate fabric into a soil backfill. The fabric layers are continued out to the face of the backfill and folded up over the edge of the covering soil layer and overlapped by the next higher layer. The fabric on the face prevents the soil from running out from between the fabric layers and friction between the soil and the fabric develops the tensile strength of the fabric and provides stability to the backfill.

The advantages of fabric retained soil walls are many. The cost of materials is reduced over conventional retaining walls. Construction methods are adaptable to remote locations and do not require heavy equipment or skilled labor. Fabric walls are flexible. Their performance would not be adversely affected by consolidation of foundation soils or relatively large lateral movements. Finally, the full strength of the fabric may be developed without deep imbedment. This characteristic makes fabric retained soil walls particularly suitable for steep sidehill construction.

To test the feasibility of fabric retained soil walls, a series of small scale laboratory model tests and two full scale field test were performed.

MODEL STUDIES

Small scale models were used to test the suitability of currently developed design procedures for application to fabric retained soil walls. Lee, et.al., (1)*, used the conventional concepts of lateral earth pressure and applied them to the design of reinforced earth walls. With minor changes, this method of analysis was applied to this study.

Figure 1 illustrates a vertical fabric retained soil wall. If the Rankine earth pressure theory is applied, lateral movement places the wedge ABC in a state of active plastic equilibrium. The lateral earth pressure, σ_h, at any depth, d, is given by $\sigma_h = K_a \gamma d$ where k_a is the Rankine active lateral earth pressure coefficient given by $\tan^2(45-\phi/2)$ and γ is the unit weight of the soil. The potential failure surface, AB, slopes upward at an angle of $\theta=45+\phi/2$. The design assumes that the tension in any fabric layer is equal to the Rankine lateral stress at the depth of the layer times the face area that the fabric layer must support. When the vertical fabric spacing is x, a unit width of fabric at depth d must support a force of $k_a \gamma dx$.

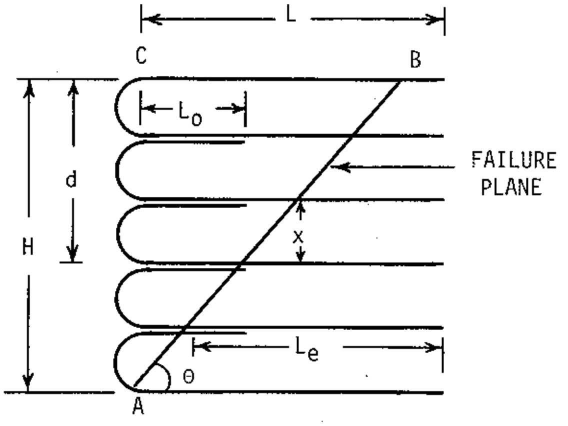

FIGURE 1 Sketch of section through a fabric retained soil wall.

The models were 0,61m wide and 0,46m high with o,41m of sand behind the wall facing. This was the smallest model that could be used without the effects of friction between the model and the sides of the box being excessive (2). A uniform fine angular quartz sand with an angle of internal friction of 38 degrees and a unit weight of 10.8 KN/m3 was used in all models.

Model walls were constructed by raining sand from a spreader into the box. The fabric layers were marked with colored sand at the plexiglas box sides. Difficulty was encountered with fabric faced models as the fine sand tended to run out around the sides. For this reason, models were also constructed with wood faces. In this type of model one fabric layer was attached to each of several horizontal grooved wood strips.

If a fabric of sufficiently low strength was used, the walls could be made to fail under their own wieght. Such a weak fabric was not abailable however, a non-woven polypropylene fabric which weighed about 10 g/m^2 was used. It had an average tensile strength of about 245 N/m. This strength required vertical surcharge loading to produce failure. A hydraulic load frame was utilized to apply the surcharge.

Since the fabric faced models were difficult and time consuming to construct, the majority of the tests were on wood faced models. Three fabric faced models were tested to compare performance of the two types. Horizontal length, vertical spacing and strength of the fabric layers were varied. The fabric layer strength was varied by using one or two sheets in each layer.

The model walls were tested by increasing the surcharge load until failure occured. The load increased to a maximum and then decreased slowly as horizontal and vertical deflections becamse excessive. This maximum load was defined as the failure load. Models that failed by tearing of the fabric did not fail suddenly. Most of the models displayed a definite failure surface as indicated by offsetting of the colored sand lenses. This surface was generally well defined near the bottom of the wall and less evident and slightly curved near the top. For an angle of internal friction of 38°, the Rankine lateral stress theory predicts the failure plane will be oriented 64° above the horizontal. The test data showed that the failure planes in the models were very close to this inclination with an average value of 62°. Tearing was generally parallel to the wall face and occurred at about the location of the failure plane. Deflections and load at failure were somewhat higher for the fabric faced models but the general mode of failure for all models was the same.

If t_s is the strength of the fabric per unit width and q_f the surcharge necessary to produce failure, the Rankine method predicts $q_f=\frac{t_s-HK_a x}{K_a x}$. This theoretical failure surcharge is compared with the actual surcharge at failure in Figure 2. The experimental surcharge values are corrected for the effects of friction between the surcharge and the top of the backfill before plotting.

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* Numbers in parentheses refer to References.

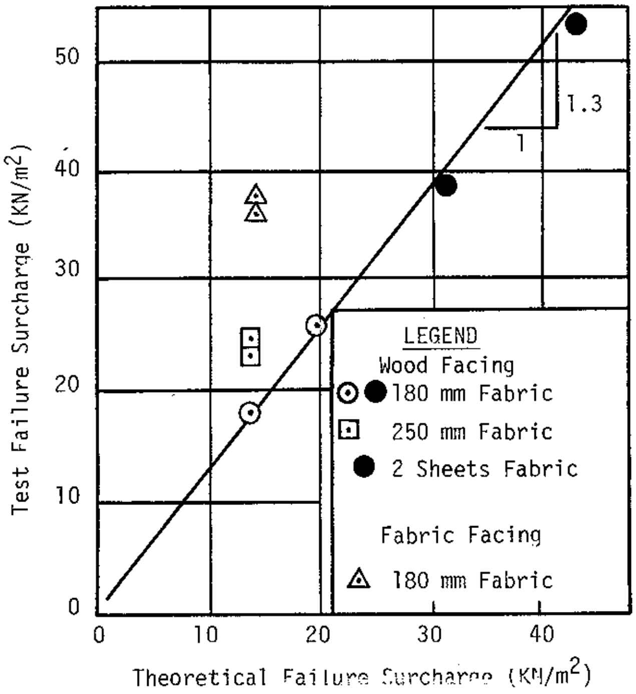

FIGURE 2 Theoretical Versus Measured Failure Surcharge for Model Tests.

Figure 2 indicates that the model walls support higher loads than predicted by theory.

There are enough uncertainties in the calculations necessary to remove the boundary effects from the model test results to cause questioning of the very high capacities indicated for some models; however, it does appear that the theory used will produce conservative estimates of fabric retained wall safety.

FIELD TESTS

The opportunity to construct the first full-size fabric retained soil wall was provided by the U.S. Forest Service when it became necessary to reconstruct a road fill above the Illinois River in Oregon, U.S.A.

Although this type wall was recognized as being "unproven and untried", the potential usefulness offset the uncertainties and the decision was made to use this reconstruction as an experiment to explore the feasibility of constructing fabric retained soil walls.

Reconstruction required a wall approximately 3,3m high and 10m long. To facilitate construction, the excavation for the wall was ramped down at 1½ to 1 slope at each end. The final wall had a center section 3,3m high and 10m long and two end sections each 5m long with their height gradually increasing from zero to 3,3m.

The original design of the fabric retained wall assumed the use of on-site materials for backfill. This material consisted of silty sand and angular gravel size rock fragments. Conservative values of 19,6KN/m^3 and of 30° were assumed for the inplace unit weight and angle of internal friction of this material. Legal duel tandem axle loads were assumed as the live loads.

The fabric in the wall is a synthetic, nonwoven, needlepunched, spunbonded polypropylene. The weight used in this construction is approximately 420 g/m^2 and the tensile strength assumed for design is 11,4 KN/m. The failure elongation is about 166%. This fabric is inexpensive and its ability to undergo very large strains and its nonwoven texture make it very resistant to damage during construction. Even tracked vehicles can move directly over it if turning movements are avoided. Coarse angular materials may be compacted over it and traveled over if a minimum thickness of twice the maximum particle size or about four inches whichever is greater is maintained over the fabric. If a small tear does develop, the nonwoven texture resists enlarging.

The fabric is permeable and when buried is resistant to rot. However, when exposed it is deteriorated by ultraviolet light. Also this fabric wall face is susceptible to vandalism; therefore, the finished wall has a gunite facing to protect it from both of these hazards.

Using the assumed material properties and the Rankine method the important wall dimensions were calculated for a factor of safety of 1.5. This low value was used because of the very conservative assumptions made with respect to other factors. As recommended by Lee (1), the estimated at rest lateral earth pressure coefficient was used instead of the active coefficient in the calculations. The resulting design called for fabric spacing, x, of 0,3m for the top 2,3m of the wall and of 0,23m for the lower part of the wall. The computed required length, L, and overlap, L_o, were 2m and 0,3m respectively. Because of the well drained nature of the fill, water pressures were assumed negligible.

The fabric for the construction was supplied in rolls 5m wide. Rather than cut it to the minimum width required, the full width was used. This gave a fabric length, L, of 3,3m and an overlap, L_o, of 1,5m. Therefore, the factor of safety with respect to safe anchorage of the fabric was higher than originally proposed and the tension in the fabric was the controlling factor. Also during actual construction a select backfill was used. This material had properties superior to those assumed in the design. For the as constructed conditions, the computed factor of safety was approximately 2.0.

Construction of the wall was undertaken in December, 1974. The first sheet of fabric was placed directly on the foundation soil.

A berm of sand was placed at the position of the front of the wall. The fabric was folded back over the berm and covered with backfill to the top of the berm. The backfill was placed by a front loader augmented by laborers with shovels. Compaction was accomplished by two track coverages by the loader. Difficulty was encountered in maintaining layer spacing and a vertical wall face by this method; therefore, after the third layer burlap bags filled with sand and placed in a row were substituted for the berm.

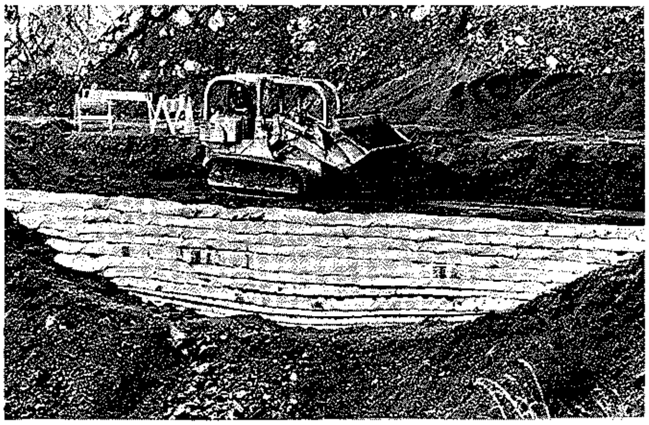

FIGURE 3 Illinois River Road Fabric Wall During Construction

This first wall was encouraging but it left many questions unanswered. Therefore, the U.S. Forest Service decided to construct a second wall near Shelton, Washington, USA. This wall would be higher and would be subjected to large live loads. It would be constructed by improved techniques and would be treated with asphalt to protect against deterioration from sunlight. Further it would be instrumented to measure wall movements and would use two fabrics with different stress-strain and creep characteristics.

The Shelton wall was approximately 60m long, increasing gradually in height from 1m at the ends to 6m in the mid-section. The backfill material was a fairly uniform 75mm crushed basalt. This material was free draining and assumed to have a density of 19.6KN/m^3 and a ϕ of 31°. The friction angle between the backfill and the fabrics was taken as 2/3 ϕ and between two sheets of the fabrics is about 20°.

One end (one half) of the wall was constructed of the same nonwoven, needlepunched, spunbonded polypropylene (Fibretex) and the other end was constructed of a nonwoven, needlepunched, spunbonded polyester (Bidim) fabric. Each fabric was used in two weights as indicated in Table 1. The polyester is stronger for the same weight but it is more expensive per pound. At the time (June, 1975) and place of this construction the costs of the two fabrics were almost identical for the same strengths. The polyester has better creep characteristics; however, the higher failure strain of the polypropylene makes is much less susceptible to damage during construction.

TABLE 1 - Fabric Properties

Fabric Type	Weight (g/m^2)	Strip Tensile Strength (KN/m)	Failure Strain (%)
Polypropylene	420	11,4	166
	600	17,2	
Polyester	230	10,7	60
	405	18,9	

The wall design used the heavy fabrics and a 0,23m layer thickness in the lower levels. Next higher the thickness was increased to 0,3m. Further up the lighter fabrics were used with a 0,23m layer. Finally the lighter fabrics and 0,3m layers were used in the top part of the wall.

The wall is on a timber haul road. The normal log trucks have a gross weight of 480 KN. The design, however, is controlled by the logging equipment which must be moved over the road. Some of this equipment weighs as much as 935 KN on four axles. These loads are infrequent; therefore, a low factor of safety of 1.25 is used in the calculations. Tension in the fabric controls the design. Consistent with the modified Rankine design method the wheel loads are assumed distributed to the wall as proposed by Spangler (3) for conventional walls. The backfill is very well drained; therefore, water pressures are assumed negligible.

Construction of this second wall was facilitated by the use of movable forms to support the wall face during construction. The forms consisted of 50x300mm timber planks retained by simple metal supports shown in Figure 4. To construct a layer, the metal supports were positioned along the front of the wall and the timbers were placed against the uprights. The fabric then was placed with sufficient length overhanging the forms to provide for the necessary overlap. Figure 5 illustrates this stage and also shows some of the instrumentation.

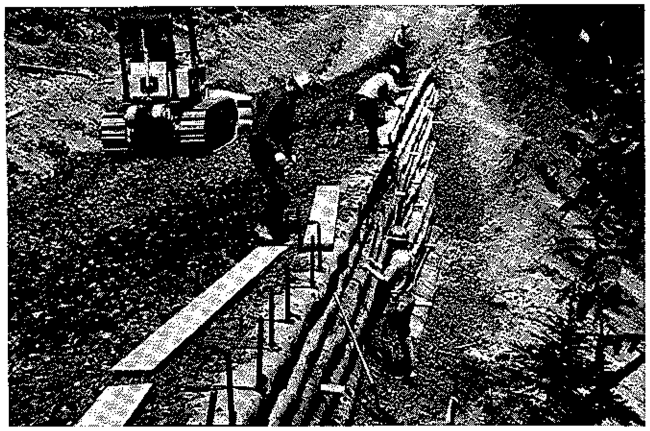

FIGURE 4 Positioning Form Supports to Start a New Wall Layer

Backfill material was placed at the front of the new layer with a front end loader and formed into a berm with shovel. The fabric was folded back over the berm and additional backfill placed and compacted by the construction traffic. Densities between 17.9 and 19.6KN/m^3 were measured. The next step was to remove the timbers and the metal supports and move them up to start the next layer (Figure 4).

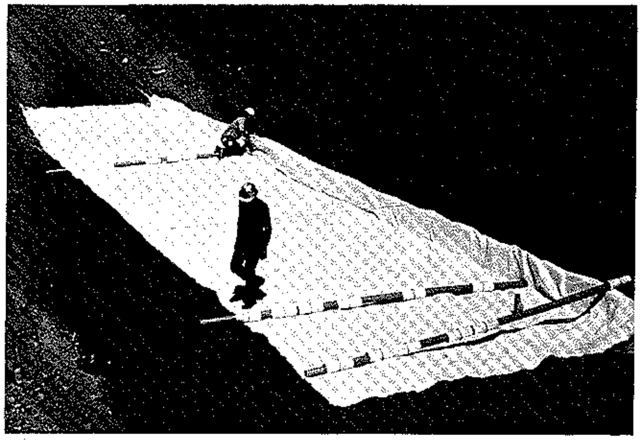

FIGURE 5 Fabric Ready for Backfill

The construction procedure worked very smoothly. The wall was constructed in 12 work days with a supervisor, three laborers, one equipment operator and the front end loader. It is very important that the fabrics be protected from ultraviolet radiation immediately after construction. This is particularly true for the polypropylene. This wall was sprayed with CSS 1 asphalt emulsion at the rate of 1 liter/m^2. This rate was the maximum that did not destroy the permeability of the fabric. Specimens of asphalted fabric have been placed on the hillside above the wall and will be tested at various times to investigate the effectiveness of the asphalt treatment.

FUGURE 6 Completed Shelton Fabric Wall

The total cost of the wall was $27 608 (1975 U.S. dollars) exclusive of the instrumentation. This included $16 129 for excavation and backfill. The wall had a face area of 197 m^2. The orginally proposed gabion wall was estimated to cost $45 000.

The polyester fabric was much more easily damaged and numerous holes were punched in it during construction. In no case, however, was the damage severe enough to impare the stability of the wall.

The wall was instrumented to measure movements. Three horizontal inclinometer tubes were installed vertically in the backfill immediately behind the wall face. Also 26 horizontal tubes with slip joints were installed as shown in Figure 5 to measure lateral and vertical movements. Loose fitting sleeves with metal rings were positioned along the tubes. The positions of the rings were located with an induction probe inserted into the tube.

The Shelton wall has been in service over a year and a half and it is performing very satisfactorily. Horizontal movements have been very small. The face has moved outward about 30mm. This movement has been within two feet of the face. Movements large enough to measure have not been indicated deeper in the backfill. Most movement occurred within the first 6 months. There are no significant differences in movements associated with the different fabrics. There is no evidence of creep in either fabric. This may result from the fact that the design was controlled by a few very large live loads and therefore, the sustained dead load produces low stresses in the fabric. Or it may be that the laboratory tests do not adequately represent the stress-strain characteristics of the fabrics when confined in a soil mass.

CONCLUSIONS

The model and field tests reported in this paper show that the fabric retained soil walls are economical and practical for certain classes of retaining wall problems and deserve further development. If used with judgment, the Rankine design method provides a satisfactory preliminary method for designing additional fabric retained wall experiments. There are still many unanswered questions includeing the questions of durability and of the effects of backfill material type; however, creep of the fabric does not appear to be as major a problem as anticipated when using this design method.

Contracts for fabric retained soil walls should include both precedural and end product requirements. There appear to be many alternative methods of controlling the wall face and the layer thickness. Contractors can be expected to contribute important innovations. The fabrics used in these projects are resistant to damage, however, contracts should include provision to protect the fabric. Procedural control of compaction for most low walls is expected to be adequate.

More work is needed to fully develop the potential of this concept. and it is hoped that this paper will encourage others to participate in this development.

ACKNOWLEDGEMENTS

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