Soil reinforcement – A tale of three walls

L'amélioration des sols – Le conte de trois murs

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SYNOPSIS. The use of soil reinforcement for construction of retaining walls is demonstrated through three case applications involving geotextile walls at a mountainous road, a Reinforced Earth wall and embankment at a landslide area, and a soil nailing wall at a bridge abutment. Steel strips, geotextile sheets and steel rods were used as reinforcing elements. The wall facings consisted of precast concrete units or a wire-mesh reinforced gunite layer. Both internal and external stabilities were considered. For internal stability, the tension capacity of the reinforcement and its pull-out resistance were analyzed. The required length of the reinforcing elements was governed by the external stability which considered the soil and its reinforcement as a coherent structure. Compared to other alternative retaining structures, the reinforced soil walls were selected based on cost, schedule, aesthetic and construction considerations.

INTRODUCTION

In conventional civil engineering practice, retaining walls are designed assuming that the wall suports the horizontal loads from the soil behind the structure and any superimposed surcharge. Recently, however, a new concept has emerged where the soil supports itself or is incorporated into the structure assuming a major structural or load-carrying function. This paper discusses three "earth walls" constructed following this concept.

REINFORCED SOIL WALLS

When properly compacted, a granular soil develops a relatively high capacity in compression and shear to make it structurally useful. Like unreinforced concrete, however, the soil is weak in tension. To overcome that weakness, reinforcing elements are introduced in the soil to form a coherent mass similar to that of reinforced concrete.

The reinforced soil walls discussed in this paper are grouped into two major classes: (a) embankment - type compacted reinforced soil walls, and (b) in-situ reinforced soil walls. Each wall has three major components: reinforcing inclusions, soil and facing elements. Different materials (metals, polymers, geotextiles) and geometries (strips, grids, sheets, rods, and fibers) provide the required reinforcement. When backfill is used, it usually consists of cohesionless free-draining soil. The types of facing currently used include precast concrete elements, metal sheets and plates, welded wire mesh, shotcrete and others.

The major advantages of reinforced soil walls are: (a) low cost, (b) simple and rapid construction, (c) no form work is required, (d) aesthetically pleasing facings, (e) flexibility and tolerance to vertical and horizontal ground movements, and for in-situ reinforced walls, top-down construction. Their main limitations include (1) durability of the reinforcing elements, (2) excessive elongation of the geosynthetics, (3) application to clayey soils where saturation and creep can affect performance, and for the compacted reinforced soil walls, large construction space required behind the wall (the length of the reinforcing elements is at least 0.7 times the wall height).

AVAILABLE WALL SYSTEMS

The most widely used compacted reinforced soil walls involve strip reinforcement (Reinforced Earth), grid reinforcement (VSL, welded wire, geogrid) or sheet reinforcement (geotextile). The in-situ reinforced soil walls include soil nailing, element walls, reticulated micro pile systems, and jet grouted walls. A discussion of all these walls is given by Munfakh (1988). A detailed study of most is provided by Mitchell

Table 1. Wall characteristics

Wall System	Reinf Type				Reinf. Material		Failure Surface			Earth Pressure Coefficient				Stress Transfer		
	Strip	Grid	Sheet	Rod	Metal	Non-Metal	Rankine	Bilinear	Wedge	K_a	K_o	K_o to K_a	0.65-0.45	Friction	Passive Resist.	Both
Reinf. Earth	●				●			●				●		●		
VSL		●			●			●				●			●	
Geotextile			●			●	●			●	●			●		
Geogrid		●				●	●			●						●
Welded Wire		●			●			●					●			●
Soil Nailing				●	●				●	●						●

and Villet (1987). Table 1 summarizes the characteristics of the most commonly used wall systems.

SOIL-REINFORCEMENT INTERACTION

The stress transfer between the soil and the reinforcement takes place through one or a combination of the following interactions: (a) friction along the soil-reinforcement surface, (b) passive soil resistance along the transverse members of the reinforcement (Fig. 1). The soil reinforcing elements can be either extensible or inextensible. In inextensible systems (Reinforced Earth, VSL, Tensar, etc.), the strains required to mobilize the full strength of the reinforcing elements are much smaller than those needed to mobilize the full strength of the soil. For extensible materials (geotextiles), the required strains are much larger. Therefore, relatively large internal deformations usually occur in these types of walls (Jones, et. al., 1987). In these cases, the soil strength properties should also be measured at large strains (residual strength).

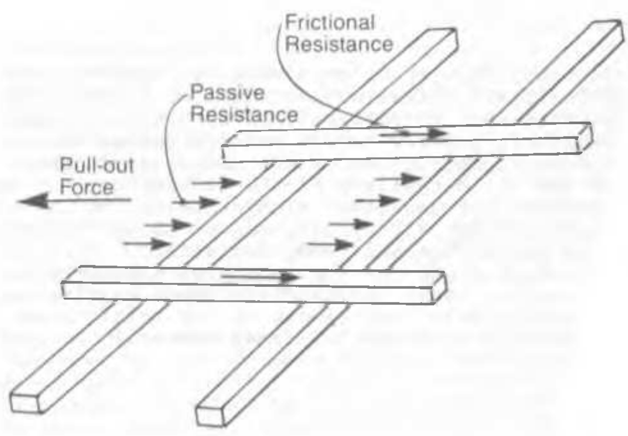

Fig. 1. Stress transfer between soil and reinforcement

DESIGN CONSIDERATIONS

The reinforced soil walls are designed to satisfy both external and internal stabilities. For external stability, the wall facing and its reinforced embankment are considered as a coherent block structure with active earth pressure acting behind the block. The stability of the block is then analyzed against sliding, overturning, bearing capacity failure and deep-seated failure.

The internal stability of the system involves evaluation of (1) the tension capacity of the reinforcing elements, (2) the pull-out resistance of the reinforcements, and (3) the resistance of the reinforcements to corrosion or other deteriorating factors. When very stiff reinforcing elements such as jet grouted nails are used, the reinforcement may be subject to tension, shear and bending moments (Schlosser, 1983).

The maximum tensile stress in the reinforcement should be less than that allowable for the material. This stress is calculated assuming horizontal equilibrium of stresses in the corresponding soil layer. The appropriate value of K used in determining the horizontal pressure in the soil layer ranges from at-rest to active depending on the degree of restraint imposed on the soil by the reinforcing elements (Table 1). In the Reinforced Earth System, K is usually taken as Ko at the surface decreasing linearly to Ka at a depth of 6 m and remaining constant below that depth. For the welded wire wall, Anderson, et. al. (1987) recommend design values of K=0.65 for the upper 4.5 m of wall height and K=0.45 for the portion of the wall below 6 m with linear interpolation in between. By analyzing instrumentation data from a number of soil nailing cases, Juran and Elias (1987) developed an analogy between the state of stress observed in nailed-soil cuts and braced excavations. They concluded that semi-empirical approaches similar to those of braced excavations can be used for determining the horizontal stresses behind the nailed-soil wall.

The potential failure surface in the reinforced soil mass differs from one system to another. The Reinforced Earth, VSL and welded wire walls assume a bilinear failure surface corresponding to the locus of the points of maximum tension in the reinforcing elements. The Rankine failure surface is usually considered when designing geotextile or geogrid walls. The failure surface separates the active zone behind the facing from the resistant zone where pull-out of the reinforcement is resisted by friction and passive soil resistance as indicated earlier. Mitchell and Villet (1987) give illustrative examples of how the pull-out resistance is calculated in a variety of soil reinforcement systems. A factor of safety of 1.5 against pull-out is usually required.

WALL 1. NORTH HALAWA VALLEY ACCESS ROAD, HAWAII

Building of the Interstate Route H-3 through the Koolau Mountain Ridge of the Hawaiian Island of Oahu involves construction of a major tunnel. To reach the remote tunnel portal location during construction, an access road was required with approximately 7800 ft. (2.4 km) of retaining walls up to 26 ft. (7.9 m) in height. To minimize the cost of the temporary construction, three alternative wall systems were designed including a gabion wall, a Reinforced Earth wall, and a geotextile wall. All retaining walls were required to have a minimum service life of 10 years and to be resistant to the moderately to highly acidic in-situ soils.

Prospective bidders were requested but not required to bid on all three retaining wall alternatives. The average bid price for the geotextile wall was approximately 32 percent less than that for the Reinforced Earth wall, and 42 percent less than that for the gabion wall. The unit cost of the geotextile wall from the overall low bid was $14.38 per sq. ft. ($154.80 per m2) of wall face (1983 price). This price included excavation, geotextile fabric, backfill and gunite facing.

The geotextile wall is constructed by placing alternate layers of geotextile fabric and granular fill. The face of the wall is formed by wrapping the fabric sheet upward and overlapping it for anchorage (Fig. 2). A wire mesh reinforced gunite cover layer provides protection to the exposed fabric, and finish to the wall face.

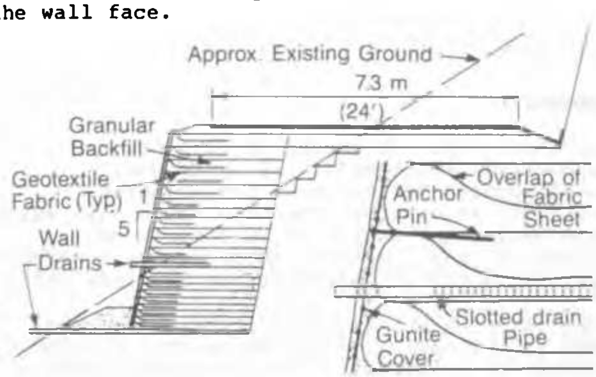

Fig. 2. Geotextile wall details

The design of the geotextile wall involved determination of the spacing, width and overlap length of the fabric layers. At-rest earth pressures and lateral pressures from surface live loads were conservatively assumed to act on the inner face of the wall. Fabric layer spacing was based on the ultimate tensile strength of the fabric assuming a factor of safety of 1.5. A minimum fabric strength of 60 lbs/inch (10.5 kN/m) as determined by the wide strip tensile test was required, resulting in vertical layer spacings of 12 inches (300 mm) to a depth of 5 ft. (1.5 m) below the top of the wall, 9 inches (230 mm) from 5 to 11 ft. (1.5 to 3.4 m), and 6 inches (150 mm) below a depth of 11 ft. (3.4 m).

Both internal and external stabilities were considered in determining the required fabric length. For internal stability, the full tensile load in the fabric layer must be resisted by soil-fabric friction along the length of fabric behind the Rankine failure wedge. The external stability, however, ultimately governed the design requiring a minimum width to height (L/H) ratio of 0.7. For depths less than 5 ft. (1.5 m) below the top of the wall, an overlap length of 4.5 ft. (1.5 m) was calculated. For greater depths, a minimum length of 3 ft. (0.9 m) was used.

The construction specifications required the use of either woven or non-woven sheets of polypropylene. No longitudinal fabric seams were permitted in construction. Transverse seams required a minimum overlap of 12 inches (0.3 m). Pervious granular material was used as backfill. Slotted PVC pipes wrapped in filter fabric were specified to facilitate collection of groundwater from the backfill and drainage through the gunite layer (Fig. 2).

WALL 2. STERLING MOUNTAIN TUNNEL, NORTH CAROLINA

The Sterling Mountain Tunnel in North Carolina carries Highway I-40 through the Blue Ridge Mountains. In March, 1985, a large rock slide destroyed the tunnel portal. After removal of the debris, an emergency action was implemented to stabilize the side of the mountain and to reopen the tunnel to traffic.

A combination of permanent rock reinforcement and horizontal drainage was used for the large-scale slope protection. To provide protection from small rock falls, a retaining wall supporting an embankment was constructed parallel to the roadway. The wall and its embankment will serve as a buffer zone between the roadway and the rock slope, absorbing the kinetic energy of the falling rocks and accumulating loose rock behind a rock fence erected above the retaining wall.

Three types of retaining walls were considered for the project: a Reinforced Earth (or VSL Retained Earth) wall, a gravity-type concrete modules wall (Doublewal), and a concrete-faced tieback wall. The completed wall would have a constant height of 35 ft. (10.6 m) above the roadway and a 90 degree end wall abutting the rock face.

Both the Reinforced Earth wall and the Doublewal required rock excavation near the portal. The tieback wall did not require rock excavation, but required difficult drilling through very hard quartzite for installation of the soldier piles and tiebacks. The cost differential between the Reinforced Earth wall and the Doublewal was within the degree of precision of a preliminary cost estimate. The tieback wall was about 60% higher in construction cost. To speed up construction, the material would have to be procured in a separate advance contract and be stored at the site. The space required for material storage was greatest for a Doublewal and least for a tieback wall.

The tieback wall alternative was eliminated because of its relatively high construction cost. Because of the tight construction schedule, and the limited space available for operation and storage of construction material, the Reinforced Earth wall was judged to be the most suitable for this project. The total construction time including materials procurement was about two months for the 208 ft. (63 m) long wall, which consisted of concrete facing panels and steel reinforcing strips in a compacted granular backfill.

WALL 3. NEW JERSEY TURNPIKE WIDENING

At Interchange 15W of Section D of the New Jersey Turnpike a ramp was required to be added under an existing bridge to accommodate traffic volume increase. To allow construction of the new lane while maintaining traffic on the bridge deck above, a top-down construction method was selected using soil nailing for excavation support. Driving of sheet piles or construction of a conventional reinforced concrete wall was more expensive and would have required removal of the bridge deck and interruption of the bridge traffic.

Fig. 3 illustrates a cross-section of the nailed-soil wall. Three rows of nails were required with vertical spacings of 2.5 to 3 ft. (0.75 to 3 m) and a horizontal spacing of 5 ft. (1.5 m). Each nail consists of a 15 ft. (4.5 m) long, No. 8 bar, installed in a 6-inch (15 cm) diameter drilled hole (Fig. 4).The entire lengths of the nails were within a compacted granular fill material.

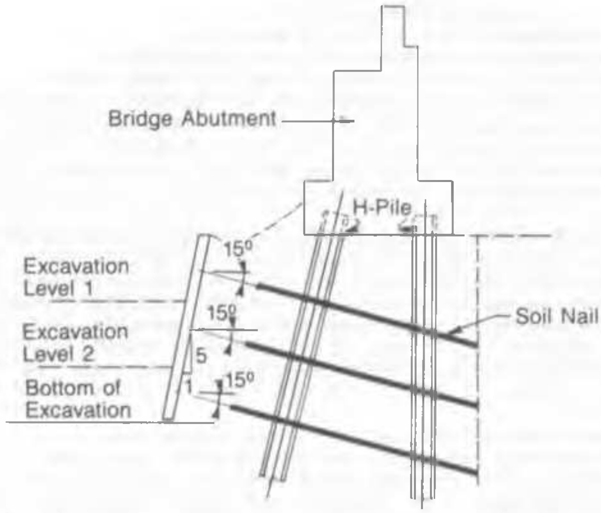

Fig. 3. Cross-section of nailed-soil wall

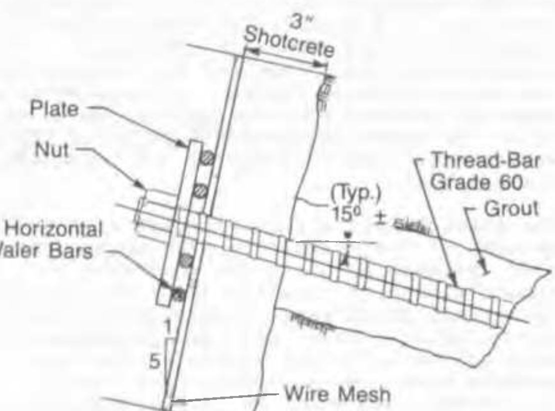

Fig. 4. Nailing details

The internal stability of the system was checked for tensile rupture of the nail and adhesion failure at the soil-nail interface. The external stability of the coherent nailed-soil structure, however, governed its design. A conservative approach using Ko was followed for determining the horizontal pressures acting on the wall face in order to prevent horizontal soil movements that may have a negative impact on the existing bridge piles behind the wall.

Construction of the soil nailing wall is performed in three repetitive stages. Each stage involves excavation of a soil layer, placing of a row of nails and shotcreting of the exposed face. A cast-in-place concrete facing provides the final wall finish. No internal drainage is required since the permanent groundwater level is below the base of the nailed-soil mass. A ditch is provided at the top of the wall to collect and drain the rainwater away from the wall face. Pull-out tests will be performed during construction to verify the tensile capacity of the nails.

SUMMARY

The three walls discussed in this paper demonstrate the benefits of using soil reinforcement for construction of earth retaining structures. The reinforced soil walls were easier and faster to construct, more economical and, in most cases, better looking than conventional cast-in-place concrete walls.

Both external and internal stabilities were used in the design of the walls. For all three cases, the length of the reinforcing elements was governed by the external stability.

Durability of the reinforcement was an important factor in selecting the wall type. Galvanized steel conforming to ASTM A-572, Grade 60 was used in the Reinforced Earth wall. A gunite cover was used at the facing of the geotextile wall to prevent deterioration of the geotextile fabric upon exposure to ultra-violet light.

Due to the increasing competition among the various wall systems, alternate bidding is recommended. Substantial savings have been realized on recent projects when alternate bidding was allowed.

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