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Landslide stabilization using geofoam

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ABSTRACT: This paper describes a landslide that utilizes geofoam and involves a single family residence near Seattle, Washington in the United States. The remediation of the slide initially involved a heavily anchored, soldier pile and timber lagging wall with rock backfill that would be extremely costly. An alternative remediation using smaller drilled-in-place piles with timber lagging held in-place with several drilled tieback anchors and lightweight geofoam block backfill was selected. The smaller wall size and cost savings made possible by the geofoam is discussed in this paper.

1 INTRODUCTION

The single-family residence is located on the west side of 11th Avenue West in Seattle, Washington overlooking the Magnolia bridge in an established residential neighborhood. The rear wall of the residence, below the basement foundation elevation, comprises a flat, but slightly inclined concrete panel extending down over a near vertical soil face. At the base of this concrete wall there is a short gently sloping "yard" area that is partially retained by a series of short timber tie retaining walls. There is also a post-supported timber deck structure extending out from the lower level of the house. These deck posts are supported on drilled-in-place concrete piers.

Historically this western slope experienced several landslide events. This activity has slowly dragged soil from around the drilled pier foundations. The loss of support allowed these piers to settle leaving the timber deck "hanging" from the rear wall of the residence, and also "pulled" the timber tie walls downslope. The soil and tie wall movement is also removing support from the base of the concrete wall along the rear of the residence and, it too, is also in jeopardy.

To combat this landslide related threat this home owner, and those of the three adjacent residences, were developing a contract for the design and construction of a "heavy" anchored soldier pile, timber lagging and rock fill retaining wall. The scale of this wall was sufficient to cause the home owner concern about the cost and he was seeking a less expensive means of stabilizing his portion of the slope. The repair involves installation of vertical and lateral support of the rear concrete panel wall to restrain the soil beneath the structure, and installation of a new anchored retaining structure to stabilize and recreate the back yard of the residence.

The first remedial step was to drill a series of Titan 30/11 anchors through the concrete panel to pin it in-place. Concurrently a series of vertical Titan 30/11 piers was drilled along the base of the concrete wall to provide vertical support. These Titan piers were structurally connected to the concrete panel wall with bolted-in-place steel brackets which were subsequently encased in concrete. This pinned the concrete panel firmly to the upper face of the western slope, and prevented the soil beneath the structure and the house foundation from future vertical or lateral movement.

The tie-back anchors were drilled to a depth of 6.1 m on 1.5 m centers at an angle of about 20 degrees. Anchor resistance, determined to be 239.5 kPa/m, was achieved in the firm and competent native silt. After grout set up the anchors were locked off by hand against a C6x15 steel C channel which acts as a waler beam. Figure 1 shows a schematic of this system.

The original deck supporting piers are connected to the existing concrete wall by "truss-like" grade beams. The loss of soil support around these piers had begun to initiate settlement, and a large portion of the deck load was transferred into the grade beams. This load transfer caused the distorting grade beams to impose an increasing lateral and vertical load on the concrete panel wall and this was beginning to

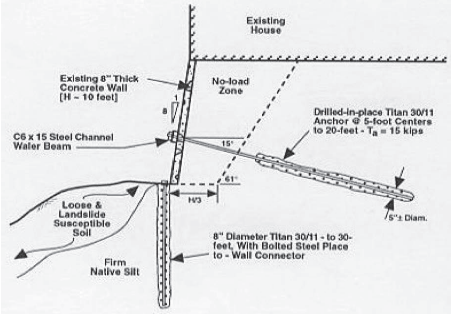

Figure 1. Schematic of underpinning and anchorage of existing concrete wall.

pull the wall off the slope face. This was one of the primary reasons for providing supplemental vertical and lateral wall support.

The ground surface drops off steeply to the west for a height of about 1.8 to 2.5 m. This near vertical drop appears to be an old landslide scarp. Beyond this drop, the site slopes downward to the west for more than 30 m.

The second retaining structure, the anchored soldier pile and lagging wall, is constructed about 3.7 m downslope of the above-described concrete wall. This retaining structure is to re-support the timber deck and recreate some usable flat back yard area. This retaining structure consists of 0.61 m diameter drilled soldier piles with timber lagging. W6 × 20 wide flange steel piles were inserted into each hole and provided a means of "retaining" the timber lagging. The pile holes were backfilled with 34,500 kPa concrete. Geofoam blocks are used to help reduce the vertical and lateral stresses on the retaining structure. Approximately 6.1 m long Titan 30/11 drilled anchors provide lateral restraint and extend into the firm and competent native silt soils. This installation is depicted in Figure 2.

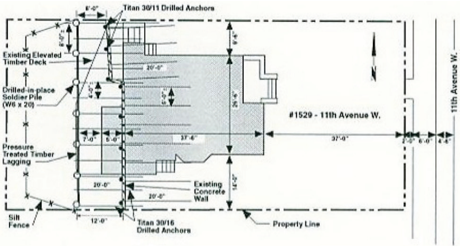

Figure 2. Plan view of the house, the two retaining structures, and the anchors.

2 SUBSURFACE CONDITIONS

Three exploratory borings provided a reasonable appreciation of the subsurface soil conditions. They typically encountered a surficial layer of very loose to loose silty sand and sand to a depth of about 1.2 m below the ground surface. Beneath this is hard silt (ML) that extends to the depth explored, i.e., 6.6 m. This hard silt contains pervasive multi-directional fracturing that may be the result of past landsliding, but which decreases with depth. Hard, intact silt ($N > 80$) is encountered at a depth of 15 feet. At the time the borings were drilled a groundwater surface was at approximately 3.65 m below the ground surface, though seasonal fluctuations may occur.

Subsequent soldier pile drilling to a maximum depth of 10.4 m along the downgrade side of the residence found similar materials. Medium dense, moist sands (SP) and silty sands (SM) extended to a depth of between about 3.4 and 6.1 m, then an approximately 1.8 to 2.1 m thick stratum of loose, saturated silty sand (SM) was found. This was underlain by very dense, moist, silty sand (SM) and a hard, moist, silt (ML). A small amount of water inflow was observed immediately atop the saturated silty sand stratum.

3 GEOFOAM BACKFILL

The second retaining structure, located downslope and to the west of the existing concrete wall, consists of drilled soldier piles with timber lagging and drilled tie-back anchors. The sloped area between the two retaining structures had to be filled to help create, and facilitate the use of, a new flat rear yard area. The possible backfill sources were soil or a lightweight fill.

Soil backfill, if used, had to be a free-draining granular material with a maximum size of 76 mm, having no more than 5% fines (silts and clay size material passing the Number 200 sieve). A soil backfill would have to have been imported. In addition, each thin (100 mm thick) backfill lift had to be compacted by hand operated compactors to a minimum of 95% of the maximum Modified Proctor dry unit weight. The soil's moisture content also had to be within 2% of the optimum moisture content. The constrained space would have made this level of compaction and compaction control difficult. Finally, the compactor could not get within 1.5 m of the rear of the anchored retaining wall to avoid generation of compaction induced earth pressures. Thus, the use of lightweight fill material was considered.

Geofoam was selected because of ease of field placement and trimming and the elimination of compaction or compaction control. Geofoam usually weighs less than 0.6 KN/m^3 and can exhibit a high compressive strength if desired. This is evident by the use of geofoam for roadway embankments (Stark et al. 2004 a and b). The geofoam was placed to a point at least 0.3 to 0.46 m below the final ground surface to prevent hydrostatic uplift and to help facilitate vegetation and/or landscaping growth.

The geofoam used here is an XPS-VII manufactured by Big Sky Insulation of Belgrade, Montana. The compressive strength at less than 2 percent axial strain is 310 kPa and the unit weight is 0.35 kN/m^3. The original Geofoam blocks were 2.4 m long, 1.2 m wide and 1.2 m thick. This thickness made the blocks difficult to handle, particularly in moderate to high wind conditions. To facilitate handling the contractor cut the blocks in half with a hot wire cutter. This size reduction allowed a single workman to lift, carry and place the individual blocks with ease [see Figure 3].

Figure 3. Geofoam block field installation.

The use of geofoam reduced the vertical stress applied to the pre-existing landslide in the back yard and reduced the earth pressures on the lower retaining structure. This allowed for smaller vertical drilled-in-place piles and timber lagging restrained by tie-back anchors and a steel waler beam instead of the original larger retaining system.

The home owner estimates that the smaller, anchored retaining structure and Geofoam backfill resulted in a savings of approximately $100,000.

4 SLOPE STABILITY ANALYSES

Static and seismic slope stability analyses were conducted to verify the adequacy and global stability of the retaining structures. The soil parameters used, shown in Table 1, were developed from the drilled soldier pier holes, the original borings, and subsequent soil testing.

The cross-section in Figure 4 depicts the geometry and materials considered in the stability analyses. Using the soil parameters in Table 1, the cross-section in Figure 4, Spencer's (1967) and Bishop's (1955) stability methods as coded in Slope/W, and the search routines in SLOPE/W, the minimum computed static and dynamic factors of safety are 2.1 and 1.3, respectively. The critical static and dynamic failure surfaces are shown in Figure 4. The pseudo-static (dynamic) analysis was conducted using a 0.2 g horizontal seismic acceleration.

Table 1. Material properties for stability analyses.

Soil Unit	Unit Weight (kN/m^3)	Friction Angle (Degrees)	Cohesion (kPa)
Silty Sand (Fill)	18.6	30	0
Shallow Silt	18.1	28	0
Sand	15.7	28	0
Hard Silt (Fractured)	19.6	28	7.2

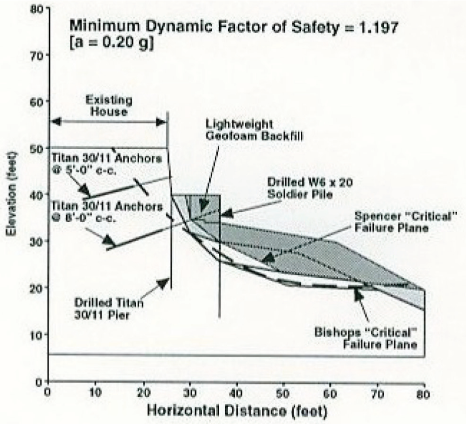

Figure 4. Slope section for stability analyses showing retaining structures, geofoam, and geologic materials.

5 FIELD PERFORMANCE

Both retaining structures have been in-place for about six years and survived a significant regional landslide in the downgrade slope without any detrimental impact. There has been some resulting loss of soil at the face of the wall necessitating the installation of two additional timber lagging planks at the base of the wall. However, there has been no apparent impact to the residence, the wall system, or the geofoam backfill from this soil loss. The current condition of the anchored wall is shown in Figure 5.

Figure 5. Existing anchored retaining wall system after nearly six years.

6 CONCLUSIONS

The initial remediation of this residential involved an extremely costly [for the home owner] heavy anchored, soldier pile and timber lagging. An alternative remediation using smaller diameter drilled-in-place piles and timber lagging restrained by drilled tie-back anchors and lightweight geofoam block backfill was used to stabilize and recreate the back yard. The geofoam reduced the vertical stress applied to the pre-existing landslide, and also reduced the lateral earth pressures on the lower retaining wall. The smaller wall size and reduced cost was made feasible because of the use of the lightweight geofoam as the backfill material.

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