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SLOPE STABILIZATION USING GEOFOAM

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ABSTRACT: This paper describes a landslide that involves a single family residence near Seattle, Washington in the United States. Remediation of the slide initially involved a heavily anchored, soldier pile and timber lagging wall that would be extremely costly for the homeowner. An alternative remediation using smaller drilled-in-place piles with timber lagging held in-place with several drilled tie-back anchors and lightweight geofoam block backfill was selected. The smaller wall size and cost was feasible because lightweight block geofoam was used as the backfill material. The static and seismic design of the wall, the wall construction, and the cost savings to the homeowner are discussed in this paper.

INTRODUCTION

The single-family residence which is the subject of this paper is located on the west side of 11th Avenue West in Seattle, Washington overlooking the Magnolia Bridge. The site is in an established residential neighborhood with similar single-family residences to the north, south, and east of the subject residence. To the west, the site comprises a heavily vegetated steep slope.

The rear wall of the residence comprises a slightly inclined 8 inch thick concrete wall that extends down to the upper portion of this steep western slope (see Figure 1). 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. These timber tie walls are typically about three to four feet high. There is also a post-supported timber deck extending out from the lower level of the house. These deck posts are supported on drilled-in-place concrete piers.

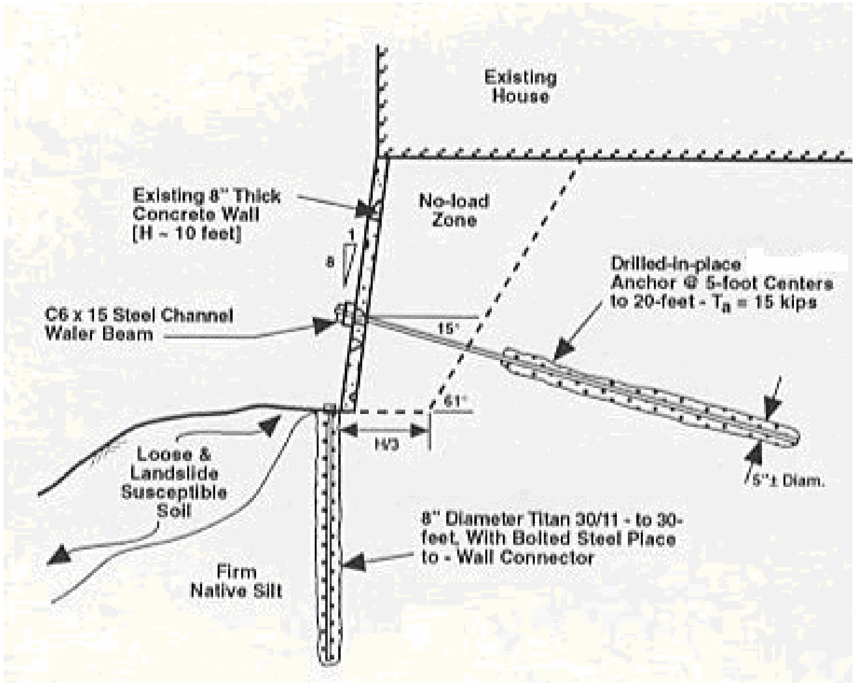

Figure 1: Schematic of underpinning and anchorage of existing concrete wall.

LANDSLIDE ACTIVITY AND STABILIZATION

The steep western slope has a long history of landslide activity and has been subject to several recent localized landslide events. The landslide activity has slowly dragged soil from around the old drilled pier foundations that help support the timber deck extending along the west side of the residence. The loss of soil support has allowed these concrete piers to settle which has left the timber deck literally "hanging" from the rear wall of the residence.

This landslide activity is extensive enough that not only the timber deck is in jeopardy, but the timber tie walls are slowly being pulled downslope and are near collapse. The movement of the soil and the tie walls is also removing support from along the base of the concrete wall along the rear of the residence and, it too, is also in jeopardy.

Because of the landslide activity, the stability of this residence, as well as three others to the south, was being slowly degraded and the potential for structural damage, or even failure, to occur was quickly increasing.

To combat the landslide related threat, this homeowner and those of the three adjacent residences were in the process of developing a contract for the design and construction of a "heavy" anchored soldier pile and timber lagging retaining wall. This wall was to retain the crest of the slope as well as the four adjacent multi-story residences. The scale of this wall was such that the homeowner was concerned about the cost and was seeking a less expensive option for stabilizing this homeowner's portion of the slope.

The project involves installation of a new anchored retaining structure in the back yard of the residence, installation of both vertical and lateral support of the rear concrete panel wall of the residence, and restraining the soil beneath the structure.

The first step in re-supporting this concrete panel wall was to install a series of drilled-in-place anchors through the concrete panel to pin it in-place (see Figure 1). Concurrent with the anchors a series of small diameter drilled-in-place vertical piers were installed along the base of the concrete wall to provide vertical support. The piers were structurally connected to the base of the concrete panel wall with bolted-in-place steel brackets. After the brackets were connected, the brackets and the tops of the piers were encased in concrete.

This combination of anchors and piers stabilized the rear flat concrete panel wall and pinned it firmly to the upper face of the western slope. This prevented the soil beneath the structure and the basal foundation of the house from future vertical and/or lateral movement.

The tie-back anchors extend to a depth of 20 feet on five foot centers at a downwards inclination of about 15 degrees (see Figure 1). The measured anchor resistance of 1.5 ksf was achieved in the firm and competent native silt soils existing beneath the residence. After the anchor grout set up, the anchors were locked off by hand against the rear face of a C6x15 steel channel which acts as a waler beam. Figure 1 shows a schematic of the underpinned and anchored existing concrete wall. Figure 2 shows a photograph of the backyard area and the existing concrete wall, including the installed anchors and waler beam.

As mentioned, there is also a series of drilled concrete piers that support an elevated timber deck structure at the level of the walkout basement of the residence. These piers are connected to the existing concrete wall by “truss-like” grade beams. Because of the loss of support around these piers they had begun to settle, and a substantial portion of the deck load was transferred into the grade beams. As a result of this load transfer, the distorting grade beams were imposing an increasing lateral and vertical load on the flat concrete panel wall and this was beginning to pull the wall off the slope face. This was one of the primary reasons for providing supplemental vertical and lateral wall support.

The site surface from the base of the concrete wall west to the face of the deck post supporting concrete piers is generally flat or gently sloping. Along the outboard face of the drilled piers the ground surface drops off steeply to near vertical for a vertical distance of about six to eight feet. This vertical drop appears to be an old landslide scarp. Beyond this vertical drop, the site slopes downward to the west at a relatively gentle to moderate grade for more than one hundred feet.

Figure 2: View of the anchors, waler beam, and encapsulated pier heads.

The second retaining structure, the anchored soldier pile and lagging wall, is constructed about twelve feet downslope of the building's existing western concrete panel wall. The main function of this retaining structure is to recreate some usable flat area in the back yard and re-support the timber deck (see Figure 3).

This retaining structure consists of two-foot diameter drilled-in-place soldier piles with timber lagging. A W6x20 wide flange steel pile was inserted into each 30 foot deep drilled hole to act as reinforcement in the buried portion of the pile and as a means of "retaining" timber lagging in the above-ground portion. The below-ground portions of these pile holes were backfilled with concrete having a 28-day compressive strength of 5,000 psi.

To reduce the original size and cost of this structure, geofoam blocks are used to reduce the earth pressure on this second retaining structure. In addition, the light weight of the geofoam backfill does not substantially increase the vertical stress at the top of the old landslide scarp. This retaining structure is also tied back with drilled-in-place anchors, which extend for a distance of approximately twenty feet behind this wall and into the firm and competent native silt soils.

The original retention system design by another consultant utilizes a much larger and more heavily anchored soldier pile and timber lagging wall because it was to be located further downslope and had a higher exposed vertical wall face. This heavier system also used a coarse crushed rock as backfill material behind the anchored segment of the wall. Although free draining, this material would have added a substantial weight to the wall and to the old landslide. This retaining structure is also tied back with relatively long drilled-in-place anchors.

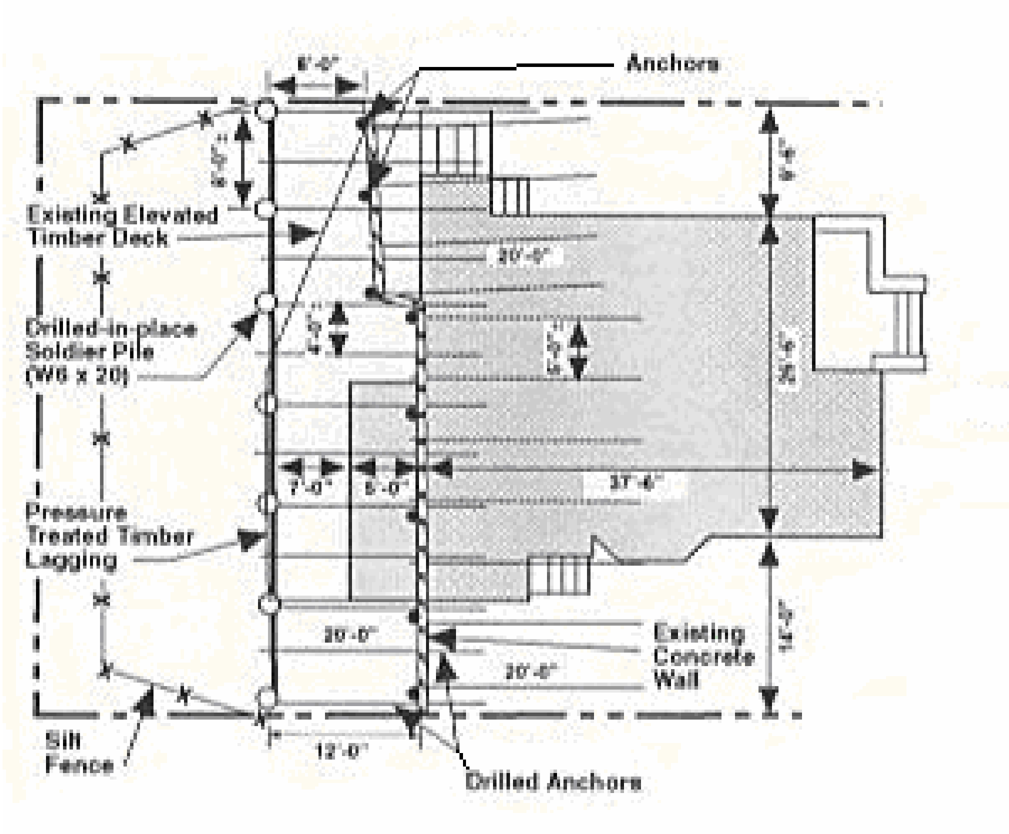

Figure 3: Plan view of the house, the two retaining structures, and the anchors.

SUBSURFACE INVESTIGATION

Three borings were drilled in the general vicinity of the subject residence to gain a reasonable appreciation of the subsurface soil conditions. The borings typically encountered a surficial layer of very loose to loose silty sand and sand that extends to a depth of about four feet below the ground surface. This silty sand and sand classify as a SM or SP according to the Unified Soil Classification System. Beneath this surficial layer is hard silt (ML) that extends to the depth explored, i.e., 21-1/2 feet. This hard silt contains pervasive multi-directional fracturing that may be the result of past landsliding or desiccation. The fracturing decreases with depth and intact hard silt (N>80) is encountered at a depth of 15 feet.

At the time the three borings were drilled the groundwater surface was approximately 12 feet below the ground surface. However, seasonal fluctuations in the groundwater surface are expected for the site.

Subsequent drilling along the downslope side of the residence for the new soldier pile holes found similar materials. Medium dense, moist sands (SP) and silty sands (SM) extend to a depth of between about 11 and 20 feet. Beneath this is an approximately 6 to 7 foot thick stratum of loose, saturated silty sand (SM), and this is underlain by very dense, moist, silty sand (SM) and a hard, moist, silt (ML). These boreholes extend to a maximum depth of 34 feet. A small amount of water inflow was observed immediately atop the saturated silty sand stratum.

GEOFOAM BACKFILL

If soil were used to backfill the second retaining structure, the specification required free-draining granular material with a maximum particle size of three inches. In addition, the backfill soil was required to have 75% passing the Number 4 sieve and no more than 5% fines (silts and clay size material passing the Number 200 sieve). If this backfill type was chosen, the material would have to be imported. In addition, the backfill had to be compacted in thin (4-inches thick) horizontal lifts by hand operated compactors. Each lift had to be compacted to a minimum of 95% of the maximum dry unit weight based on the Modified Proctor compaction energy. In addition, the moisture content of the soil backfill had to be within 2% of the optimum moisture content. This level of compaction and compaction control would be difficult in the confined and sloping back yard. Finally, the compaction could not get within 5 feet of the rear of the anchored retaining wall because compaction induced earth pressures could develop and impact the retaining structure. Thus, the use of lightweight fill material was considered.

Geofoam was selected because of ease of placement and trimming in the field and because no compaction or compaction control is required. Geofoam usually weighs less than 4 pcf and can exhibit a high compressive strength if desired. This is evident by the use of geofoam for roadway embankments (Stark et al. 2004). The geofoam was placed at least twelve to eighteen inches below the ground surface to prevent hydrostatic uplift and facilitate vegetation and/or landscaping.

The compressive strength of the geofoam at less than 2 percent axial strain is 45 psi and the unit weight is 2.2 pcf. The dimensions of the geofoam blocks used on this project are 8 feet long, 4 feet wide and 4 feet thick. The 4-foot thickness proved 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 4).

The use of geofoam not only reduced the vertical stress applied to the pre-existing landslide in the back yard but also reduced the lateral earth pressures on the second retaining structure. The reduced earth pressure allowed for use of a series of smaller vertical drilled-in-place piles with timber lagging held in-place with several drilled tie-back anchors and a steel waler beam instead of the much larger retaining structure than was originally designed.

The homeowner estimates that the smaller, anchored retaining structure and utilization of geofoam resulted in a savings of approximately $100,000.

Figure 4. Geofoam block field installation

SLOPE STABILITY ANALYSES

To verify the adequacy of the retaining structures and the stability of the back yard slope, static and seismic slope stability analyses were conducted. The soil parameters used in the analyses are shown in Table 1 and were developed from the original borings, drilled soldier pier holes, and subsequent laboratory soil testing.

Table 1: Material properties for stability analyses

Soil Unit	Unit Weight (pcf)	Friction Angle (degrees)	Cohesion (psf)
Silty Sand (Fill)	120	30	0
Shallow Silt	115	28	0
Sand	100	28	0
Hard Silt (Fractured)	125	28	150

The cross-section in Figure 5 presents the geometry and materials considered in the stability analyses. Using the soil parameters in Table 1, Spencer's (1967) and Bishop's (1955) stability methods as coded in Slope/W, and the cross-section in Figure 5, the minimum static factor of safety is 2.1. The critical static failure surfaces obtained using Bishop's (lower solid line) and Spencer's (upper solid line) stability methods are also shown in Figure 5. These critical surfaces occur downslope of the existing wall which is in good agreement with field observations. The dashed failure surface in Figure 5 was also analyzed to investigate the global stability of the repair.

The pseudo-static (dynamic) analysis was conducted using a horizontal seismic acceleration of 0.2g and the critical static failure surfaces. The minimum computed pseudo-static factor of safety is 1.3.

In summary, the stability analyses indicate that both the anchored and vertical pile supported concrete wall, and the new anchored soldier pile and timber lagging wall should be stable under both static and seismic conditions.

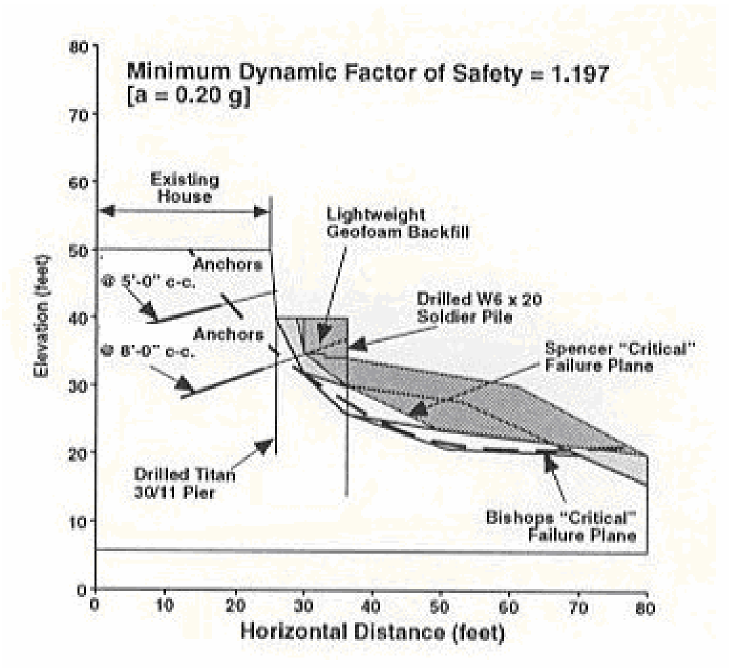

Figure 5. Cross-section for stability analyses.

FIELD PERFORMANCE

Both retaining structures have been in-place for about seven years. The geofoam retaining structure is the furthest downslope and has survived a large downslope movement (a regional landslide failure of the downgrade slope) without any detrimental impact. This large downslope movement was apparently induced by the installation of the “heavy” retaining system by adjacent homeowners. There has been some loss of soil from along the face of the wall due to the downslope soil movement associated with the large landslide event. This necessitated the installation of two additional timber lagging planks at the base of the wall to retain the exposed soil. 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 6.

CONCLUSIONS

This paper describes a landslide involving a single family residence in Seattle, Washington in the United States. The remediation of the slide initially involved a heavy anchored, soldier pile and timber lagging wall that would have been extremely costly for the homeowner. An alternative design using smaller diameter drilled-in-place piles with timber lagging, held in-place with several drilled tie-back anchors, and lightweight geofoam block backfill was selected. The geofoam not only reduced the vertical stress applied to the pre-existing landslide(s) in the back yard of the residence, but also reduced the lateral earth pressures on a second [lower] retaining structure constructed to create a flat or level back yard. The smaller wall size and reduced cost was made feasible because of the use of the lightweight geofoam as the backfill material.

Figure 6: Existing anchored retaining wall system after nearly six years.

ACKNOWLEDGMENT

The contents and views in this paper are the authors and do not necessarily reflect those of any of the homeowners, consultants, or anyone else involved in this project.

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