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GEOTEXTILE WALLS IN MOUNTAINOUS TERRAIN
MURS DE SOUTENEMENT DE GEOTEXTILE SUR TERRAINS MONTAGNEUX
GEOTEXTILBEWEHRTE STÜTZMAUERN IM GEBIRGE

For construction of a tunnel approach road in mountainous terrain in Hawaii, USA, three non-conventional retaining wall systems were considered: a Reinforced Earth wall, a gabion wall, and a geotextile fabric wall. The geotextile wall consists of layers of compacted granular material reinforced with non-woven geotextile fabric sheets placed between the soil layers. A wire mesh reinforced gunite layer provides protection to the exposed face. Slotted PVC pipes wrapped in filter fabric are used for collection and drainage of the groundwater. Design of the geotextile wall involved determination of the fabric layer spacing, total length, and overlay length. Wide strip tensile test was specified for measuring the required fabric strength. The bid price of the geotextile wall was significantly lower than those of the other two alternatives.

Für die Errichtung einer ZufahrtsstraBe durch einen Tunnel auf Hawaii, U.S.A., haben wir drei Stützmauer Syststeme in Betracht gezogen: ein verstärktes Erdwand, einer Schanzkorbwand, und eine Geotextiliewand, Die Geotextiliewand besteht aus lagen von kompaktierten lagen von körnigem Matrial, verstärkt mit einlagen von ungewobenen Geotechnischen matrial zwischen den einzenen Erdlagen. Ein mit Stahlgewebe verstärkter Schleuderbetonwurf schützt die AuBenhaut des Erdttammes. Perforrierte PVC-Rohre, umwickelt mit Filterstoff, sorgen für die Entwässerung der Anlage. Die Planung der Geotextilwand ervordehrte die Entscheidung über die Einlage abstände gesammt Längen und Uberlappung berreicht. Breitstreifen-zugspannung briefung wurde zur Feststellung der Zugfestigkeit der Geotextile einlagen festgesetzt. Der Angebotpreis für das Geotextile system war bedeutend niedriger als der die anderen Systeme.

INTRODUCTION

A major highway to be constructed on the Hawaiian Island of Oahu will traverse the Koolau Range, a continuous mountain ridge extending more than 850 m (2800 ft) above sea level, which separates the northeast coast from the rest of the island. (See Figure 1). The highway, designated as Interstate Route H-3, requires a 1.6 km (1.0 mile) long tunnel, and 15 km (9.4 miles) of approach roadways joining the tunnel to existing highways. The west approach to the tunnel will follow the coarse of the North Halawa Stream within a narrow, steep-sided valley. The east approach will climb the sheer cliffs, or "pali", on the windward side of the island.

Access to the remote tunnel portal locations during construction will be provided by temporary access roads which, unlike the viaducts for the completed highway, will be cut-and-fill embankments constructed along the steep mountainsides. Because of the extreme topographic relief, the west access road, alone, requires approximately 2.4 km (7800 ft) of retaining walls, constructed to heights of up to 7.9 m (26 ft). To minimize the cost of the temporary construction, three alternative retaining wall systems were designed, including a gabion wall, a Reinforced Earth wall, and a geotextile fabric wall.

Contractor bids for construction of the temporary access road along the west approach were received in May, 1983. However, the construction is presently being delayed pending the resolution of a legal suit relating to the environmental impact of the project.

This paper describes the three alternative wall systems, and highlights, in particular, the design and construction specifications for the geotextile fabric wall. Also presented is a cost comparison of the three alternatives using cost data from contractor bids for construction of the west access road.

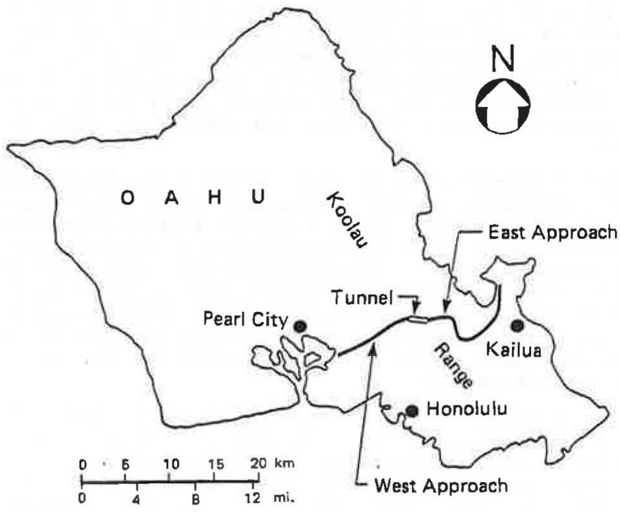

Figure 1. Location Plan

SITE CONDITIONS

The Koolau Range is composed predominantly of basalt formed by lava flows, but also includes intrusive dikes and pyroclastic rocks. The lava beds are generally between 3 and 24 m (10 and 80 ft) thick, and have dips ranging from 3 to 10 degrees. Because of the subtropical climate and heavy rainfall on Oahu, the rock surface is weathered to depths typically between 15 and 30 m (50 and 100 ft). Soil cover in the rugged mountain areas, however, is generally less than 25 cm (10 inches) thick.

Stream valleys cutting the flanks of the range are underlain by alluvial and colluvial deposits resulting from the erosion of the rock slopes above the valley. Along the North Halawa Valley, these deposits are composed primarily of highly plastic gravelly clay containing numerous rock fragments.

The difficult access along the proposed alignment precluded the drilling of exploratory borings during design of the temporary access road. These borings will be taken during construction, as the access road advances up the valley. The boring information is particularly important for confirmation of assumed subsurface conditions, and assessment of the need for excavation support such as rock bolts.

RETAINING WALL ALTERNATIVES

Table 1 presents a summary of the retaining wall requirements for the North Halawa Valley access road. Retaining walls were required in all areas with natural slopes steeper than 2.5H:1.0V (2.5 Horizontal to 1.0 Vertical). The highest retaining walls are located in areas where the ground slope is as steep as 1.0H:1.0V.

Although considered "temporary" construction, all retaining wall systems were required to have a minimum service life of ten years, to accommodate a long construction schedule and possible delays to construction. All wall systems were required to be resistant to the moderately to highly acidic in-situ soils.

Figure 2 presents a typical cross section of the gabion retaining wall alternative developed from standard design procedures for this type of wall. The wall is constructed using steel wire baskets filled with stone and arranged in a manner to form a gravity-type wall. The maximum height of the gabion wall is 7.3 m (24 ft), with a corresponding maximum base width of 4.1 m (13.5 ft). A notable feature of this alternative is the use of a geotextile filter fabric beneath and behind the gabion wall to prevent loss of soil through voids in the rock fill. Also, good quality rock fill, resistant to possible crushing or chemical deterioration, was required. Good quality rock, however, is relatively expensive and difficult to obtain on Oahu.

Figure 3 presents a typical cross section of the Reinforced Earth alternative. In this construction, slender steel strips are placed horizontally within a granular backfill to provide resistance to the horizontal forces acting on the wall face. The maximum height of the Reinforced Earth wall is 7.9 m (26 ft), with a corresponding maximum base width of 3.5 m (11.5 ft) and a maximum top width of 6.1 m (20 ft). A notable feature of this alternative is the use of cold rolled, galvanized steel face panels instead of the conventional and more costly precast concrete panels.

Figure 4 presents a typical. cross section of the geotextile fabric retaining wall. The fabric wall is a flexible, earth reinforcing system 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 (Figure 5). Friction between the soil and the fabric provides lateral resistance to prevent outward displacement of the wall face. A gunite cover layer provides protection to the exposed fabric, and finish to the wall face.

The past ten years have witnessed a rapidly increasing use of geotextile fabric retaining walls, primarily for temporary or infrequently used roads (2, 5), but also for permanent construction (1, 3). Reasons for this increased use of fabric walls are: 1) low cost, 2) easy and quick construction, 3) minimal construction equipment and material requirements, and 4) acceptable performance for the life and purpose of the structures. When constructed, the North Halawa Valley access road will make the most extensive utilization of geotextile fabric retaining walls to date.

TABLE 1 ESTIMATED LENGTHS FOR RETAINING WALLS OF VARIOUS HEIGHTS

Approx. Ground Slope	Wall Height	Approx. Length of Wall
2.0H : 1.0V	3.0 to 3.7m (10 to 12 ft)	690m (2250 ft)
1.5H : 1.0V	4.6 to 5.5m (15 to 18 ft)	1020m (3340 ft)
1.0H : 1.0V	6.1 to 7.3m (20 to 24 ft)	670m (2200 ft)

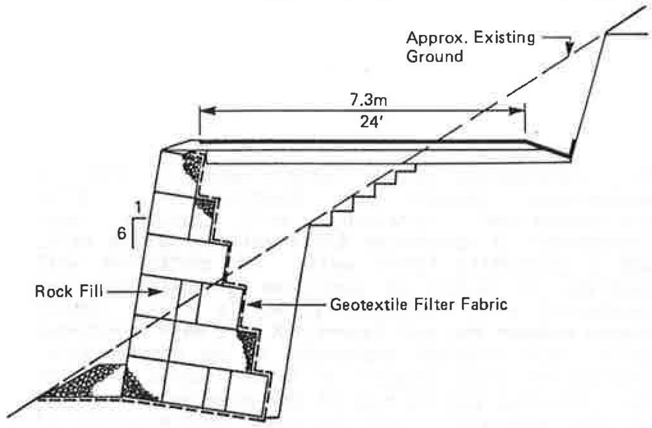

Figure 2. Gabion Wall – Typical Section

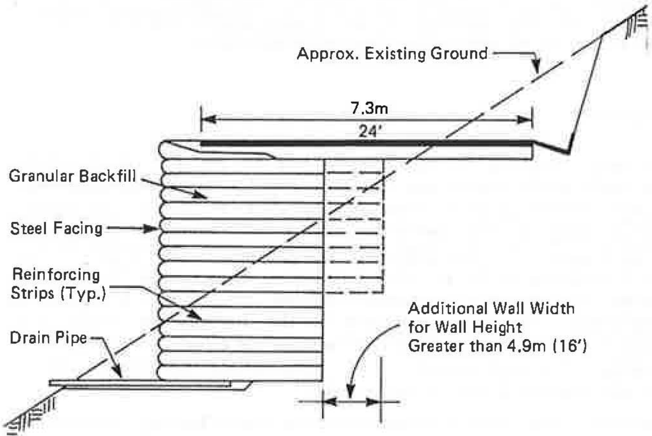

Figure 3. Reinforced Earth Wall – Typical Section

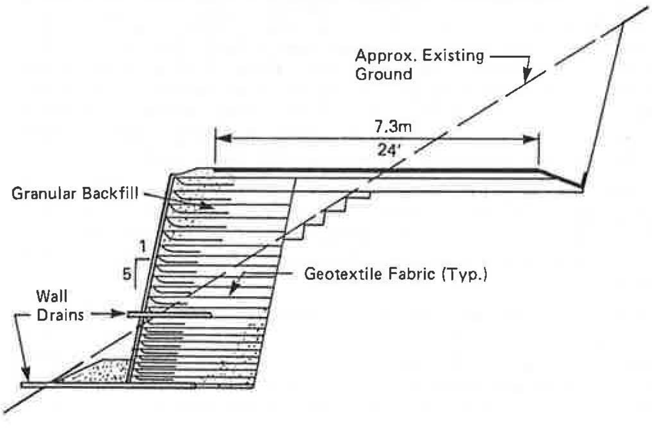

Figure 4. Geotextile Fabric Retaining Wall – Typical Section

DESIGN OF GEOTEXTILE FABRIC WALL

The design of the geotextile fabric retaining wall followed the procedures outlined by Bell et al. (2) and Steward et al. (5). In this method, illustrated in Figure 6, at-rest lateral earth pressures and lateral pressures from surface live loads are assumed to act on the inner face of the wall. Fabric layer spacing is computed from the following equation:

$$X = \frac{S}{(F.S.)\,(\sigma_h)} \qquad (1)$$

Where S = ultimate tensile strength of the fabric
σ_h = lateral earth pressure at the depth of the fabric sheet
F.S. = factor of safety = 1.5

For the North Halawa Valley access road a minimum fabric strength of 10.5 kN/m (60 lbs./inch), as determined by the Wide Strip Tensile Test, was required. Based upon this strength, the required vertical spacing of fabric layers was 300 mm (12 inches) to a depth of 1.5 m (5 ft) below the top of the wall, 230 mm (9 inches) from 1.5 to 3.4 m (5 to 11 ft), and 150 mm (6 inches) below a depth of 3.4 m (11 ft).

The length, L, of the fabric layers was determined from analyses of both internal and external stability. For internal stability, the full tensile load in the fabric layer must be resisted by soil-fabric friction in the length, L_e, of fabric behind the Rankine failure wedge (block ABC in Figure 6). Applying the same factor of safety on embedment as on fabric strength, the minimum embedded length is determined by the following equation:

$$L_e = \frac{S}{2d\gamma \tan 2/3\,\emptyset} \qquad (2)$$

Where d = depth to fabric sheet
γ = unit weight of backfill
$\emptyset$ = angle of internal friction of backfill

External stability, however, ultimately governed the length of the fabric layers. External stability, which considers overturning, sliding and bearing capacity, generally required a minimum width to height ratio (L/H) of the wall of 0.60. For the maximum wall height of 6.1m (20 ft), a L/H value of 0.55 was permitted since walls of this height would only be constructed if the rock excavation was self-supporting, or supported by the installation of rock bolts.

The required width, L, of the fabric wall was 2.3 m (7.5 ft) for walls up to 3.0 m (10 ft) high, 2.7 m (9.0 ft) for walls 3.0 to 4.6 m (10 to 15 ft) high, and 3.4 m (11 ft) for walls 4.6 to 6.1 m (15 to 20 ft) high.

Overlap length, L_o, for anchorage of the fabric sheet behind the face of the wall is determined from the following equation:

$$L_o = \frac{(F.S.)\sigma_h X}{2d_f \gamma \tan 2/3\,\emptyset} \qquad (3)$$

Where X = fabric layer spacing
d_f = depth to overlap
F.S. = 1.5

For depths less than 1.5 m (5.0 ft) below the top of the wall, an overlap length of 1.4 m (4.5 ft) is required. For greater depths, the minimum length of 0.9 m (3.0 ft) is used (5).

CONSTRUCTION SPECIFICATIONS

The Wide Strip Tensile Test was specified for measuring the required fabric strength. The Wide Strip Tensile Test (4) is performed on a 200 mm (8 inch) wide sample using jaws which are spaced 200 mm (8 inches) apart, and clamped for the full width of the fabric. This test is considered more appropriate than conventional grab strength tests since it more closely approximates the plane strain conditions anticipated in the retaining wall structure.

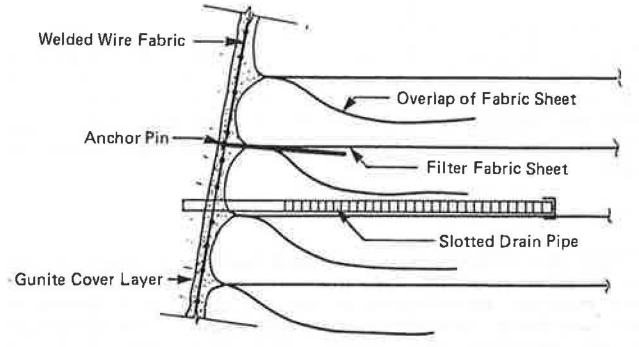

Figure 5. Fabric Wall Details

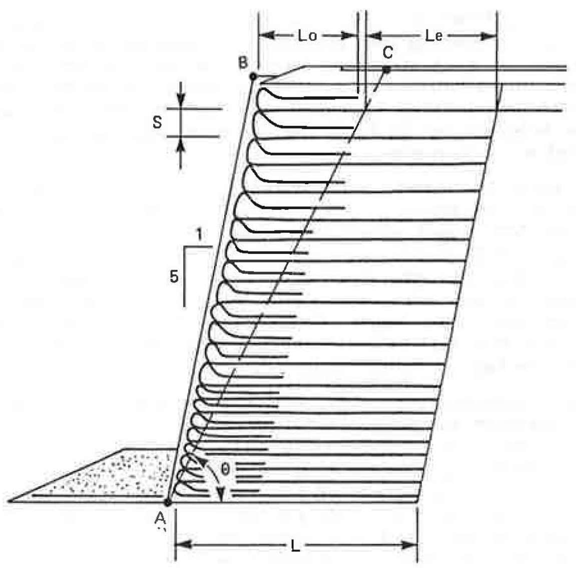

Figure 6. Fabric Wall Parameters

In addition to the Wide Strip Tensile Strength requirements previously discussed, the specifications also require the fabric to be non-woven sheets of polypropylene yarn with the following properties:

Weight: 200 g/m^2 (6 oz/sq yd), min.
Thickness: 0.40 mm (16 mils), min.
Grab Strength (ASTM D1682): 670 N (150 lbs.), min.
Equivalent Opening Size: between 0.090 and 0.212 mm

These properties are typical of the higher strength fabrics required for the retaining wall, and also assure strength against puncture or tearing during installation.

No longitudinal fabric seams are permitted in construction. Transverse seams require a minimum overlap of 0.3 m (12 inches).

Important considerations in the design of geotextile fabric retaining walls, particularly in a wet, subtropical environment, are face protection and drainage. The exposed face of the fabric wall must be protected against deterioration from UV light, and possible damage from vandelism. For the North Halawa Valley retaining walls this protection is provided by a minimum 40 mm (1.5 inch) thick layer of wire mesh reinforced gunite, as illustrated in Figure 5.

The specified backfill for the retaining walls is a pervious, granular material with maximum size of 76 mm (3 inches), and not more than 15 percent passing the No. 200 sieve (0.075 mm size opening). Slotted PVC pipes wrapped in filter fabric (Figure 5) facilitate collection of groundwater from the backfill and drainage through the gunite facing. Particular attention was given to avoiding concentrated flows of water, either from the roadway surface or from the drain pipes, which may lead to local erosion of the natural ground slope below the wall.

COST ANALYSES

Prospective bidders were requested, but not required to bid on all three retaining wall alternatives. In evaluation of the bids, however, the bid price of only the lowest cost alternative was considered. This amount was then added to the bid prices of the numerous other items which were common to all alternatives to determine the total bid amount. Although contractors bid on three retaining wall alternatives, only one type of retaining wall would be selected and used throughout the project.

Table 2 summarizes the contractor bid amounts for the three alternative retaining wall systems. The amounts shown include the cost of excavation and backfill, as well as the cost of manufactured wall elements. Common items, such as excavation support and roadway pavement, are not included. Five bids were received for each of the retaining wall systems, from a total of six contractors.

The geotextile fabric wall system received the lowest bid from all contractors except for one who elected not to bid on the fabric wall alternative. The average bid amount for the geotextile fabric wall alternative was approximately 32 percent less than the Reinforced Earth wall alternative, and 42 percent less than the gabion wall alternative. The low bid for the entire length of the North Halawa Valley access road was $US 7.37 million, including $US 1.68 million for the geotextile fabric retaining walls.

Table 3 summarizes the bid amounts for the four pay items included under the geotextile fabric wall alternative. As shown in the table, the bid amounts for excavation and backfill were highly variable, and represented a major portion of the retaining wall cost. The unit price bid for geotextile fabric ranged from $US 1.20 per m^2 ($US 1.00 per sq. yd.), which was offered by three bidders, to $US 2.28 per m^2 ($US 1.90 per sq. yd.) which was offered by the overall low bidder. The unit price bid for the gunite facing ranged from $US 21.50 to $US 32.30 per m^2 ($US 2.00 to $US 3.00 per sq. ft.).

The unit cost of the geotextile fabric retaining wall, including excavation, geotextile fabric, backfill and gunite facing, ranged from $US 89.80 to $US 241.50 per m^2 ($US 8.34 to $US 22.43 per sq. ft.) for 10,830 m^2 (116,600 sq. ft.) of wall face. The unit cost of the geotextile fabric wall from the overall low bid was $US 154.80 per m^2 ($US 14.38 per sq. ft.) of wall face.

TABLE 2: SUMMARY OF CONTRACTOR BIDS FOR RETAINING WALL ALTERNATIVES

	1983 Bid Amount ($US x 10^6) Low	High	Average
Gabion Wall	2.04	2.84	2.51
Reinforced Earth Wall	1.87	2.94	2.34
Geotextile Fabric Wall	0.97	2.62	1.77

CONCLUSIONS

Construction of the North Halawa Valley access road in Hawaii, U.S.A. requires building of 850 m (2800 ft) of retaining walls up to 7.9 m (26 ft) high along steep mountainsides.

To minimize construction cost, three retaining wall alternatives were designed and submitted to the contractors for bidding. They included a gabion wall, a Reinforced Earth wall and a geotextile fabric wall. The geotextile wall received the lowest bid.

Design of the geotextile wall involved determination of the fabric layer spacing, total length, and overlap length. Both internal and external stability were considered in determining the required length of the fabric layers. A minimum width to height (L/H) ratio of 0.60 was required. For the maximum wall height of 6.1 m (20 ft), a L/H value of 0.55 was permitted with the condition that the rock excavation be self-supported or supported by rock bolts.

Wide strip tensile test was specified for measuring the required fabric strength. Protection of the exposed face is provided by a wire mesh reinforced gunite layer. Slotted PVC pipes wrapped in filter fabric facilitates collection of groundwater from the granular backfill and drainage through the gunite facing.

The unit cost of the geotextile fabric wall from the overall low bid was $154.80 per m^2 ($14.38 per sq. ft.) of wall face.

TABLE 3: COST SUMMARY FOR GEOTEXTILE FABRIC RETAINING WALL

Item	Quantity	1983 Bid Prices: Low Unit Price* ($US)	Low Total ($USx10^3)	Average Unit Price ($US)	Average Total ($USx10^3)
Excavation	21,940 m^3 (28,700 cu. yd.)	6.80 (5.20)	149	16.36 (12.51)	359
Fabric	209,540 m^2 (250,620 sq. yd.)	1.20 (1.00)	251	1.48 (1.24)	311
Backfill	33,020 m^3 (43,190 cu. yd.)	8.50 (6.50)	281	24.46 (18.70)	808
Gunite Facing	10,830 m^2 (116,600 sq. ft.)	26.91 (2.50)	291	26.70 (2.48)	289
Retaining Wall Totals:			972		1767

* Unit prices shown correspond to amounts from the lowest total bid for Geotextile Fabric Retaining Wall.

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