

Experiences with Mechanically Stabilized Structures and Native Soil Backfill

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Practices and experience with mechanically stabilized backfill retaining structures typically using native soil backfill on low and moderate standard rural roads by the U.S. Department of Agriculture, Forest Service, are documented. Information is provided describing innovative and low-cost alternative earth-reinforced retaining structures, including welded wire walls, chainlink fencing walls, geotextile walls, and walls faced with materials such as timbers, tires, hay bales, geocells, and concrete blocks. The design process has involved either generic or custom in-house designs, or proprietary designs with custom site adaptation and materials evaluation. Local, often marginal-quality backfill material is typically used. Its use is discussed, along with advantages and problems with marginal materials. Selected case histories with various wall types and backfill materials are presented.

The three basic objectives of this paper are to

- Document that the U.S. Department of Agriculture (USDA), Forest Service, has successfully constructed hundreds of mechanically stabilized backfill (MSB) structures nationwide over the past 20 years, typically using native soil backfill. These walls and reinforced fills, built with a wide variety of designs and construction materials, have performed well overall and satisfied their intended use.
- Discuss the Forest Service's retaining structure design process, and the merits and trade-offs of custom designs and use of in-house geotechnical personnel versus the use of commercial vendors and proprietary designs for structures.
- Document the successful use of local, often marginal backfill materials in most structures, and to discuss the advantages, disadvantages, and limitations of the use of marginal materials.

Considerable experience and knowledge have been gained in the use of relatively low-cost retaining structures for construction or repairs of rural roads with space constraints, particularly in steep mountainous terrain and unstable ground. Site access is often difficult and locations are remote, making the use of geosynthetics and soil reinforcement concepts, modular or prefabricated components, and on-site backfill materials highly desirable.

Composite facing and reinforcement elements used with on-site backfill material offer substantial cost and construction advantages over many conventional retaining structures. Simple construction techniques are desired and often necessary. Minimizing cost is often an objective. MSB structures discussed here are ideal for forest or rural applications as well as for many private, local, and public road and highway needs.

A wide variety of retaining structures has been used. Wall types, typically up to 7.5 m (25 ft) high, have included welded wire walls,

geotextile walls, chainlink fencing walls, lightweight sawdust walls, and walls faced with segmental concrete blocks, hay bales, tires, geocells, or timbers. Some soil-reinforced rigid concrete face panel structures have also been used. Reinforced fills with local embankment material have been an economical alternative to walls in some areas. Considerations for each of these types of structures are briefly discussed. Selected case histories that represent a range of structures and backfill materials used are presented.

Many walls are designed in house by geotechnical personnel using available design methodologies to take advantage of custom designs, risk assessment, and cost savings of earth reinforcement systems and local materials. Other walls are designed and constructed using readily available manufacturers' standard designs, along with laboratory testing to ensure that backfill material meets design parameters. Drainage is nearly always incorporated into designs, commonly with geocomposite drains. Filtration, durability, and transmissibility requirements for the geocomposite drainage systems are specified.

Local backfill material is most often used on Forest Service projects. Fortunately typical soils found in a mountain environment have a high friction angle, satisfying needed design strength criteria. However, fine-grained native soils can present design and construction problems, such as unacceptable deformation, poor compaction and drainage, and some risk. Nevertheless they may offer significant cost savings over conventional coarse granular backfill. Fine silty sands to silts with some clay and soils with up to 50 percent fines have successfully been used as backfill.

DESIGN PROCESS

One of three basic design approaches is used on Forest Service projects.

1. Custom retaining structures are selected, designed and constructed, or contracted by the Forest Service with technical input from in-house geotechnical personnel;
2. Vendor-provided structures and designs are selected by the Forest Service, with technical input from geotechnical personnel on wall type, loading conditions, foundation and site evaluation, and so forth or;
3. A consultant-, contractor-, or vendor-provided design, with some site evaluation, is used with the approval of the Forest Service. Geotechnical personnel may or may not be involved in the process.

Most structures built have used either the first or second approach. Basic retaining structure selection and design information have been documented in the Forest Service *Retaining Wall Design Guide* (1).

The design process, type and thoroughness of site evaluation, and wall selection usually depend on the skills of the personnel involved in the project. Geotechnical personnel are not common in the Forest Service agency. Most regional offices have either an individual or small staff of geotechnical personnel. A few individual forests in the West have a staff geotechnical engineer or an engineer who is responsible for several forests. In any event, the geotechnical personnel are involved in a wide range of projects and are spread thin, and time and project involvement are always limited. Thus the time committed to any project depends on the current workload and priorities, and available time may dictate what type of retaining structure and design process to use.

The main advantages of custom in-house designs with unique structures include

- The ability to evaluate the full range of available structures,
- The ability to use local or surplus construction materials,
- The ability to realize the maximum cost savings, and
- An opportunity to advance the professional state-of-the-design practice, combining practical application with research and development.

Additional advantages of having geotechnical personnel knowledgeable of soil reinforcement concepts involved include the following:

- Staff has the opportunity to perform all aspects of the project, including site investigation, foundation assessment, materials evaluation, construction control, drainage needs, and external and global stability analysis, as well as overall design and details.
- Design and construction field changed conditions can be better evaluated and accommodated.
- The risk and trade-offs of various types of structures and materials used can be better assessed.
- Current developments by other agencies and within the profession can be used and implemented.
- Proper limitations and applications of earth reinforcement concepts can be made, and misuse avoided.

The following are the advantages of using vendor products or manufacturer's standard designs:

- Standard designs and trial solutions can be evaluated quickly.
- Good construction support is likely, which commonly goes along with use of manufacturers' products.
- With limited time and resources, internal design is satisfied, though perhaps conservatively, so available time can be spent on external and global stability, foundation conditions, and other project aspects.

In reality, the use of vendor-supplied designs and products has been satisfactory and necessary at times and has cost the agency only a limited amount of money. The differential construction cost of a vendor's wall versus custom-designed walls has typically been about \$30 to \$50 per square meter (a few dollars per square foot) of face. However, the minimum cost of a vendor-provided wall has been around \$180/m² (\$17/ft²), and minimum in-house designed walls (geotextile walls) have cost \$110/m² (\$10/ft²) of wall face. Still the major advantages of having in-house expertise are overall cost-effectiveness, the total evaluation that can be accomplished, and the flexibility it offers.

The actual design process used by agency geotechnical personnel has depended on time, information available, and type of wall desired. Most early geotextile-reinforced and chainlink fencing wall designs were based on the ultimate strength design method developed by the Forest Service (2). Welded wire walls were designed by or followed design tables developed by the Hilfiker Company or now use design information such as that presented in NCHRP 290 (3). Reinforced fill designs have used methods involving modified slope stability limit equilibrium analysis (4).

Today many design procedures are being proposed, refining the earlier relatively conservative design methods. A recommended synthesis of design procedures has been presented by FHWA (5). Also, generic and product specific PC based computer programs are available to facilitate the design process. For low- to medium-height structures, the standard designs available from manufacturers or the generic designs for low geotextile walls with given backfill and loading conditions (6) are very simple to use and practical in many applications. Note, however, that many manufacturer's PC programs are product specific and do not allow the user to check calculations independently.

MSB STRUCTURES

Many recent innovative designs have been developed using soil reinforcement concepts, and numerous walls have been built on rural roads using a variety of reinforcing, facing, and backfill materials. Of the walls constructed by the Forest Service in the past decade, MSB structures have been used at least 80 percent of the time, mainly because of cost and ease of construction. Most use local or on-site backfill material and easily fabricated flexible reinforcement elements. For walls less than 7.5 m (25 ft) high, cost has typically ranged from \$160 to \$270/m² (\$15 to \$25/ft²) of face. Both frictional reinforcement systems (i.e., geotextiles) and passive resistance reinforcement systems (i.e., welded wire and geogrids) are commonly used.

Walls are often located on landslides or on sites with minimal foundation information, so some limited wall deformation is desirable. Site and foundation investigations are rare for small walls. Soil-reinforced structures that minimize foundation pressures, have relatively wide foundations, and tolerate deformation are desirable. Brief descriptions of many of the MSB structures used by the Forest Service follow.

For wall drainage, geocomposite drains have been successfully and extensively used since 1975. They are particularly applicable where the excavated back slope is steep or nearly vertical, making conventional gravel drains difficult to construct. Geocomposite drains on several wall sites in California, instrumented since 1984, have performed very well. Results reported elsewhere (7,8) show that many geocomposite drains available today have good crushing strength properties and adequate flow capacity and satisfy needed filtration criteria. However, available products performance varies considerably. The drains themselves cost \$20 to \$45/m² (\$2 to \$4/ft²), installed.

Welded Wire Walls

Welded wire walls up to 9 m (30 ft) high are the most commonly used MSB system in the Forest Service (Figure 1). These walls have also been constructed to heights greater than 27 m (90 ft). Many

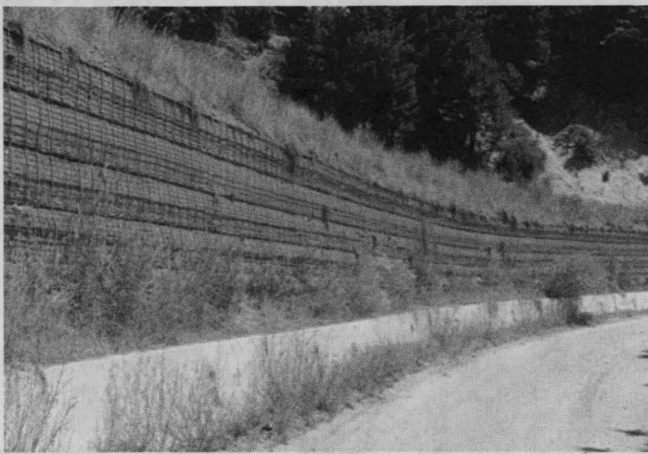


FIGURE 1 Seven-year-old welded wire wall with some face settlement due to use of native soil backfill (Plumas National Forest, California).

contractors are familiar with their assembly and local manufacturers' representatives have provided excellent construction support services to contractors, with technical advice and by providing on-the-job training to contractors. They are relatively easy to construct on grades and curves, can be adapted to many sites, can have a 50- to 75-year design life, and have often been used for bridge abutments and around culverts. Again, design information is readily available (3).

Use of fine backfill material in welded wire walls has occasionally led to vertical face settlement, from poor compaction along the wall face and from fine soil migration through the wire face of the wall. A layer of heavy ultraviolet-resistant geotextile is now usually placed against the wire mesh to contain the fine soil near the face. Use of tamped pea gravel or coarse material in the face zone will further minimize this problem and is generally recommended.

Limited experience has been gained on projects with welded wire soil reinforcement and use of rigid precast concrete face panels. The panels form a durable aesthetic wall facing. However the rigid panels are sensitive to foundation settlement and any face deformation. Select backfill is recommended with this facing system.

Geotextile Walls

Geotextile-reinforced soil walls were pioneered by the Forest Service in 1974. They have perhaps the least expensive materials cost of any wall available. For reinforcement materials alone, the cost is as low as \$15/m² (\$1.25/ft²) of wall face. Design procedures are widely published (1-3). These procedures have led to many successful and perhaps conservative designs for walls 3 to 6 m (10 to 20 ft) high or higher.

Reinforcement lift thickness (compacted) typically varies from 15 to 45 cm (6 to 18 in.). Thicker lifts are difficult to form. Base geotextile embedment length is typically nominal for pullout resistance and is dictated by the length required to resist sliding failure in external stability calculations.

Because of the flexibility of geotextiles, temporary forms must be used to support the wall face as each lift is constructed, making this process somewhat slow and labor intensive. Long 5- by 30-cm (2 by 12-in.) lumber and metal brackets are usually used for the forms.

Most geotextiles must be protected from long-term degradation by sunlight. A guniting layer is often applied to the wall face. In remote forest applications, a protective coating of asphalt emulsion may be specified, which must be repeated several times during its service life. The final wall face itself usually has an irregular shape, but its appearance is acceptable in most rural settings. This type of wall is also ideal for temporary construction applications.

Geogrid walls have been built using a design concept very similar to that used for geotextile walls, where additional strength and less creep are desired for a high wall or a stronger, more durable facing is wanted.

Lightweight Geotextile Walls

Several walls up to 8.5 m (28 ft) high have been constructed in Oregon and Washington using wood chips or sawdust. This material, wrapped in a geotextile, produced a lightweight structure ideal for placement on an active slide deposit. Design and construction procedures for this wall were roughly similar to those of a normal geotextile wall since wood chips have a high friction angle (25 to 40 degrees, based on triaxial tests). Wood chips were spread and compacted in 45-cm (18-in.) lifts between the reinforcing layers. Compaction was difficult to measure so a procedural specification of several passes per lift was used. A final typical moist density of approximately 6.3 kN/m³ (40 pcf) was achieved.

Gradation of the wood backfill used has ranged from fairly clean 75-mm (3-in.) maximum size chips to a fairly dirty sawdust. Performance has been satisfactory and settlement of the material after 10 years has been limited to about 5 percent of the structure height as slow decomposition continues.

Chainlink Fencing Walls

Several chainlink fencing walls up to 6.7 m (22 ft) high have been constructed by the Forest Service using conventional 9-gauge galvanized chainlink fencing material placed in 30- to 60-cm (12- to 24-in.) lifts in the backfill material for reinforcing.

Pullout resistance and strength parameters for custom design of the chainlink wall are similar to those of a welded wire material. The construction procedures for forming the face are similar to those used for a geotextile wall. A 6-mm (1/4-in.) galvanized screen is placed at the wall face to confine the backfill material. Hay bales have also been used to form temporarily the face of this type of wall.

Timber-Faced Walls

An ideal type of reinforced soil wall appears to be one incorporating the ease and cost savings of geotextiles or geogrid reinforcement with durable and aesthetic timber or other facing members. A geotextile-timber wall developed in Colorado (9) appears to be a nearly ideal combination of materials (geotextile and railroad ties) that is easy to construct, aesthetic, and cost-effective. Several such walls, up to 5.5 m (18 ft) high, have been constructed by the Forest Service and appear pleasingly rustic and particularly appropriate for a rural or forest setting (Figure 2). However, because timbers are treated with wood preservatives, this type of wall facing system is not used near water courses.

The connection detail of the reinforcing material to the timbers varies. Techniques have included sandwiching the geotextile or



FIGURE 2 Timber-faced geogrid-reinforced wall in forest setting constructed with native soil backfill (San Juan National Forest, Colorado).

geogrid between the timbers, stapling the material to the timbers, wrapping it around the timbers and adding a face plate, and using an intermediate wrapped board sandwiched between the main timbers. Each facing connection technique has proven to be adequately strong for low to moderate-height walls given the relatively low lateral stress on the wall face with frequently spaced, extensible reinforcing materials (10). Timbers are often pinned together with spikes or rebar.

Segmental Concrete Block-Faced Walls

A wide variety of concrete block facings exists today; they are typically used with geogrid reinforcement. This combination of materials is easy to construct, cost-effective, and aesthetic, particularly in rocky areas. The walls have only recently been built by the Forest Service, using manufacturer-provided designs.

The connection detail of holding the geogrid in place with dowels set into the blocks is simple, easy to construct, and generally effective. Other face-connection techniques involve sandwiching the reinforcement between the blocks or shear keys in the blocks. On relatively high walls with native backfill, a drain should be located behind the backfill and behind the concrete blocks as recommended by manufacturers. State-of-the-practice information on use and limitations of segmental concrete block walls is presented elsewhere (11).

Tire-Faced Walls

Several tire-faced, earth-reinforced walls, up to 3.1 m (10 ft) high, have been designed and constructed by the Forest Service in northern California, using a slit-film woven geotextile reinforcement with used tires for the facing members. Because used tires are plentiful and free, geotextile is inexpensive; because construction is simple, the cost of this type of low wall is minimal. This type of wall is particularly easy to build with in-house crews or local hand labor, with minimal construction equipment, and is ideal for applications such as road shoulder support.

The design consists of layers of geotextile on a 19- to 38-cm (8- to 15-in.) vertical spacing placed between every one or two rows of tires. Tires are staggered on top of each other. Soil is compacted behind each layer of tires in 18- to 20-cm (7- to 8-in.) lifts. Local material is backfilled into each tire and hand compacted, filling effectively only the middle "hole" in the tire (12).

This type of wall needs to be built with a nearly 1H:4V face batter and tires staggered horizontally, one-half tire diameter on each successive layer, to prevent the backfill soil from falling through the hole and space between tires on the next lower layer. The stagger and vertical offset of the tires can provide planting space in the tire holes for vegetation, adding long-term biotechnical stabilization to the wall and improving appearance.

Settlement of the tire face is a limitation for this type of wall. After more than 5 years of monitoring one wall, deformation appears acceptable, with face settlement on the top row of tires of about 0.3 m (1 ft), or 10 percent of the wall height. Soil and pockets of vegetation have partially masked the tires.

Geocell-Faced Walls

Several geocell-type walls have been constructed by the Forest Service up to 6 m (20 ft) high since 1988. Walls have been either gravity structures or "zoned" gravity (geocell-reinforced) structures where some geocell layers extend into the backfill. These, geogrid and geotextile-reinforced geocell-faced wall designs, and testing information are discussed elsewhere (13).

The geocell fill and backfill materials have been native granular material. The cells provide confinement for loose, granular soils. The lightweight expandable cells are ideal for moving the material to remote sites. With a battered wall face, each "cell" forms a planter for vegetation. The dark or tan high-density polyethylene material has reasonable resistance to deterioration.

Reinforced Fills

Reinforced fills placed with a 1H:1V or steeper face slope have offered an economical alternative to retaining structures for those sites where the ground is too steep for a conventional fill slope yet is flat enough for a reinforced fill. Reinforced fill heights have ranged from 5 to 15 m (15 to 50 ft) on forest projects, and over twice this height elsewhere.

USE OF LOCAL BACKFILL MATERIAL

On-site or local materials, often of marginal quality, are consistently and successfully used by the Forest Service for backfill in retaining structures and reinforced embankments. They are desirable because of the unavailability or expense of imported materials. "Marginal" soils are defined as fine-grained, low-plasticity materials that may be difficult to compact, have poor drainage, or have strength parameters sensitive to density.

Coarse rock fill material, occasionally available, is excellent for backfill if it is well graded. Material with a 15-cm (6-in.) maximum size is commonly specified. However, rock fill often has enough oversize material to make layer placement difficult and to damage the reinforcement material. Free-draining rock fill is necessary only in special applications such as in coastal or streamside structures subject to periodic inundation.

Select granular free-draining backfill material, commonly specified by wall manufacturers, can be expensive to import. The cost advantage of using local material or material excavated on site can be significant, particularly in rural areas. The average cost of local backfill material, reflecting materials, placement, compaction, and haul cost, is estimated at \$10.50/m³ (\$8/yd³), compared with imported select backfill at roughly \$23.50/m³ (\$18/yd³). Given a medium-sized structure with 140 m² (1,500 ft²) of wall face and an estimated backfill quantity of 575 m³ (750 yd³) the differential cost, or savings, is \$7,500. Some of the savings may be offset by increased construction costs. However, nationwide, hundreds of thousands of dollars could be saved annually by using local backfill materials.

Select Material

Relatively clean free-draining granular soils are generally recommended by manufacturers and preferred by contractors as backfill for retaining structures. Select backfill material requirements recommended by AASHTO (14) for reinforced structures conform to the following gradation limits:

Sieve Size	Percentage Passing
10 cm (4 in.)	100
No. 40	0–60
No. 200	0–15

The plasticity index (PI) as determined by AASHTO T-90 should not exceed 6. The material should exhibit an angle of internal friction of not less than 34 degrees, at a compacted density of 95 percent of AASHTO T-99. No testing is needed for backfill where 80 percent of the material is larger than 1.9 cm (3/4 in.). The material should be free of organic matter or other deleterious materials. Requirements also include other durability and corrosion considerations. Note that some agencies recommend use of material 1.9 cm (3/4 in.) or smaller to prevent geosynthetic reinforcement damage.

Some manufacturers, such as the Reinforced Earth Company (Terre Armee Int.), will occasionally allow use of "intermediate" soils containing up to 40 percent fines, provided that the PI does not exceed 30 (15). Use of intermediate soils is limited to special cases, particularly outside the United States, where select materials are not available. With intermediate soils, specific design, evaluation, and careful construction control are required. Select material specifications are typically used, particularly where deformation must be minimized and where rigid face panels are used.

Marginal Backfill Material

Under many circumstances essentially any nonplastic to moderate plasticity, frictional soil can be used as backfill, provided the wall is designed to resist the external and internal forces. In remote areas it is generally more economical to use local native or fine-grained backfill, with drainage, and design for those appropriate strength parameters than to import select free-draining materials.

When fine-grained or marginal material is used as a wall backfill, several factors must be considered:

- The structure should be specifically designed for the strength properties of that material.
- Care should be taken to closely control placement moisture content and density.

- A well-designed and thorough drainage system should be included.
- The likelihood of accelerated corrosion must be evaluated.
- Relatively slow construction is likely, and slight to moderate formation and face settlement should be expected.

Known or documented failures (16) of soil reinforced walls with marginal or clay backfill material (which incidentally are uncommon) have ignored or overlooked one of these factors.

Local "marginal" materials used by the Forest Service have varied from silty sands to silts and clays [SM, SC, ML, and CL (Unified Soil Classification)] with over 50 percent fines (passing the No. 200 sieve) and a PI of up to 15. Marginal silt and clayey soils have been successfully used and evaluated by FHWA in its full-scale tests on the behavior of reinforced soil (10) and in the Denver test walls by the University of Colorado and the Colorado Department of Transportation (17).

Marginal materials should be specifically tested to determine their strength properties and strength-density relationship. Peak shear strength parameters should be used for analysis. Experience with marginal backfill has been favorable, but use can present problems in construction and long-term performance. Compaction of fine-grained soils is sensitive to moisture content, so close construction control is needed and the specified densities (typically 95 percent of AASHTO T-99) may be difficult to achieve. Construction delays may occur. However, once compaction is achieved, results have generally been satisfactory. Frost heave in cold regions can also be a problem under some circumstances.

Inability to achieve the specified compaction near the wall face, loss of fines through the face, or soil compressibility have resulted in some face settlement of structures. Most measured settlement has occurred in the first 2 years after construction, with minimal additional long-term settlement. Measured settlements have been 2 to 4 percent of the wall height.

Surface drainage should be designed to keep water from infiltrating into the backfill. With fine-grained low-permeability backfills, long-term saturation of the fill in a wet environment is possible, even with a drain installed behind the structure. To prevent saturation, layers of free-draining gravel can be built into the backfill. (However, this will add to the wall cost.) To prevent surface water from entering the fill, the backfill material may be waterproofed with a paved roadway surfacing.

Table 1 shows examples of local marginal soils that have been used successfully in Forest Service structures. Note that the soils, though fine grained, have good frictional characteristics and were compacted.

In view of the existing information and overall good performance of many MSB structures using marginal, fine-grained, low- to moderate-plasticity soil, it appears that industry standards could be modified to reflect this information and to realize the economic benefit of their use. Existing standards could include select material specifications suitable for high-risk and high structures or those with little tolerance to deformation or differential settlement. Most structures could be constructed using a standard (intermediate) backfill material, with limits such as 50 percent fines, a PI of 20 or less, and a minimum peak effective friction angle of 25 to 30 degrees.

Clay-Rich Cohesive Backfill Material

Generally poor-quality, clay-rich, cohesive soils with low frictional strength should not be used in retaining structures. Exceptions may

TABLE 1 Local Marginal Materials used in Forest Service Structures

Site & Forest	Wall Type (Height, m.)	USC	% Minus 200	PI	Phi' deg	c' kPa	Comments
Goat Hill Plumas NF	Welded Wire (4.6 m.)	SM	21	5	34	9.6	4% Settlement on Face, Most in 2 of the 10 Lifts.
		SC	20	8	31	14.4	
		SM	23	4	27	16.7	
Mosquito R. Tahoe NF	Welded Wire (8.2 m.)	SM	22	NP	-	-	Minor Settle- ment, Vegetated.
		ML	50	6			
L.North Fork Plumas NF	Reinforced Fill (1:1) (15.2 m.)	SM	38	2	34	4.8	Minor Slumping, Well Vegetated.
		ML	55	3	33	7.2	
Gallatin Lassen NF	HSE-Concrete Face/W. Wire (3.8 m.)	GW	1+	NP	30+	-	Minor Face Panel Separation using Light Cinder Fill
B.Longville Plumas NF	Welded Wire (5.5 m.)	CL- SM	50+	-	26	9.6	Poor Foundation, 3 % Settlement.
Grave Plumas NF	Geotextile (2.7 m.)	SM	26	NP	35	40.7	Irregular Face, Weathering Cloth but no Fill Loss.
		SM	15	NP	38	26.3	
Butt Valley Plumas NF	Tire-Faced (3.1 m.)	SC	38	8	26	19.2	10% Face Settlement.
Thomjack Klamath NF	Timber-Faced (4.6 m.)	SM	27	NP	30+	0	Minimal Settlement.
Stump Spring Sierra NF	Welded Wire (6.8 m.)	SM-					Performing Well, Min. Settlement.
		SC	42	15	-	-	
Pulga Plumas NF	Welded Wire (5.9 m.)	SM- GM	44	4	29	9.6	Mod. Settlement, Poor Compaction.
Agness Siskiyou NF	Chainlink Fencing (to 6.7 m.)	GM- SM	15	NP	-	-	Min. Settlement, Min. Corrosion, Face Vegetated.
Camp 5 Hill Willamette NF	Wood Chips+ Geotextile (8.5 m.)	GP	0	NP	34	0	5% Settlement, Continuing Chips Decomposition.

Note: Peak Phi' and c' are from Consolidated-Undrained tests @ 95% of
T-99 Density. $1 \text{ kN/m}^2 = 20.9 \text{ psf}$, $1 \text{ m} = 3.28 \text{ ft}$, NP = Nonplastic

include special circumstances of low risk, substantial cost savings, and under conditions of careful design evaluation, construction control, drainage, and monitoring. Use of clay-rich backfill material will likely present problems and will perhaps be more trouble and costly than it is worth. However, cohesive soils have good strength properties when kept dry and have been used in some reinforced

structures and reinforced embankments worldwide with moderate success and with significant cost savings (18).

The use of poorly drained backfill materials in reinforced soil structures has been reviewed elsewhere (19). Use of cohesive backfill materials presents design and construction difficulties, making drainage and compaction difficult to achieve, and deformation must

be expected and acceptable. The material must be compacted under relatively dry weather conditions and should be compacted dry of optimum. Ideally the soil should be encapsulated to disperse surface runoff and prevent the saturation of the material through microfissures filling with water.

Large surface deformations from plastic embankment materials suggest that the reinforcement should be longer than that used for conventional materials. Inextensible reinforcement can help minimize deformations. Pore pressure buildup may occur, which can reduce the frictional resistance of the backfill, so relatively high factors of safety should be used in design. Poorly drained soils can cause significantly accelerated corrosion rates in materials.

Walls with clayey soils for backfill can be designed, but long-term creep, deformation, and lateral earth pressures are difficult to predict. Walls should be constructed with a batter or a stepped flexible face to accommodate the expected deformation. Expansive clays should be avoided or modified. Forces on face connections may be relatively large. Clay-rich material can more successfully be used in reinforced fills than walls because face deformation is seldom an issue in fills.

In structures with clay-rich backfill material, the use of frequently spaced reinforcing layers and thick needle-punch nonwoven geotextiles appears desirable to add a "wicking" effect to the structure and allow for some pore pressure dissipation, especially during construction.

SELECTED CASE HISTORIES

Case History 1

Site: Stump Springs #11, #14, Sierra National Forest, Shaver Lake, California: Date constructed: 1983, Wall type: welded wire, 1:6 batter, Wall height: 4.5–6.8 m (15–22 ft).

The backfill material is fine silty sand (SM) to a clayey sand (SC) with up to 42 percent fines and a PI of 15. The soil is a fine decomposed granite, and specified compaction was 95 percent of AASHTO T-99.

Numerous slides, washouts, and roadway fill failures occurred during a major storm. Repairs included construction of a reinforced fill, two concrete crib walls, and five welded wire walls. Welded wire walls were chosen because of their relatively low cost, flexibility, and ease of construction. Manufacturers' designs were selected, and geocomposite drains were installed behind the walls and flow was monitored.

To date all walls and drainage systems have performed well. No sign of deformation is seen on the paved road above the welded wire walls. Overall settlement is 3 percent of the wall height, resulting in some typical face bulging in the wire in specific lifts.

Case History 2

Site: Grave site, Plumas National Forest, Oroville, California: Date constructed: 1987, Wall type: geotextile wall 1:6 batter, Wall height: 2.7 m (9 ft).

The backfill material is coarse to fine, nonplastic silty sand (SM) with up to 26 percent fines. Soil is a decomposed granite excavated on site, compacted to 90 percent of T-180. A geocomposite drain was placed behind the backfill.

The site was a small roadway fill failure that occurred as a result of a heavy rain. A retaining structure was needed to provide adequate roadway width and keep the toe of the fill out of a creek. A geotextile wall was chosen because of the low cost, remote area, and

simplicity of construction. A lightweight needle-punch, nonwoven geotextile was used, placed in 15- and 23-cm (6- and 9-in.) lifts, and treated with asphalt emulsion on the face. The Forest Service design procedure was used.

To date the wall has performed well with some bulging of each lift, face irregularity, and overall 7 percent face settlement. Exposed face geotextile has deteriorated slightly, and animals have chewed small holes in the face, but with no loss of backfill material.

Case History 3

Site: Butt Valley, Plumas National Forest, Canyon Dam, California: Date constructed: 1988, Wall type: tire-faced geotextile wall, Wall height: 3.1 m (10 ft).

The backfill material is a local gravelly clayey sand, with 30 to 38 percent fines and a PI of 8 to 9, derived from metamorphic rock. Field compaction was 93 to 95 percent of AASHTO T-99.

This small roadway fill failure area required a retaining structure. Since a local contractor had access to used tires and several "gravity" tire structures had been recently built, an MSB wall was designed, using tires as the facing material. A lightweight slit-film woven geotextile was chosen for reinforcement and placed between each two layers of tires. Sixteen vertical rows of tires were used. Tires are held in place by friction between tire layers or the geotextile. The bottom half of the wall is vertical, but because of soil loss around the tires, the upper half has a 1:4 batter.

Face settlement has been surveyed and monitored since construction. No settlement is evident in the roadway on top of the wall, but midwall face settlement has been about 10 percent of the wall height. Most settlement occurred in the first 2 years after construction. Today the wall appears stable and partially vegetated.

Case History 4

Site: Camp 5 Hill, Willamette National Forest, Oakridge, Oregon: Date constructed: 1984, Wall type: geotextile wall with lightweight fill (wood chips), Wall height: 8.5 m (28 ft).

The backfill material is wood chips [7.5 cm max. (3 in.)], having a friction angle of about 34 degrees and dry unit weight of 6.3 kN/m³ (40 pcf). Procedural compaction was used, with a specified number of roller passes per lift.

The lightweight geotextile reinforced wall was constructed in a large, active slide area where bearing pressure needed to be minimized, the flexibility of a geotextile wall was advantageous, and the wall could conform to the site. The custom design was based on the frictional characteristics of the chips, using a Forest Service-developed design procedure. The slit-film woven geotextile was sprayed with asphalt emulsion for protection, but poor adhesion resulted with this type of geotextile.

To date the geotextile wall has performed well and overall settlement has been about 0.5 m (1.5 ft), or 5 percent of the total height. Gradual settlement continues as the chips decompose with some moisture in the chips. The geotextile is disintegrating, but because of minimal face pressure, no chip loss has occurred. The historic slide has not moved.

Case History 5

Site: Gallatin Marina, Lassen National Forest, Eagle Lake, California: Date constructed: 1989,

Wall type: rigid concrete panel facing with welded wire soil reinforcement, Wall height: 3.8 m (12.5 ft).

The backfill material is a well-graded to poorly graded, nonplastic, coarse sandy gravel (GW) with minimal fines. The materials are soft lightweight volcanic cinders that partially break down during compaction, doubling the percentage of sand-size particles.

The Hilfiker Stabilized Embankment precast concrete panel wall type with a smooth, gravel-textured face, was selected and designed by the contractor to satisfy the need for a durable, aesthetic wall facing along a marina walkway. Changed site conditions caused modification of the initial wall design and materials source. Panels are 0.8 by 3.8 m (2.5 by 12.5 ft), connected to the welded wire reinforcement with pins. The soft foundation was overexcavated to bedrock and backfilled with cinders. A geocomposite drain was installed behind the backfill. Compaction was difficult to control with the lightweight backfill material but was reasonably achieved.

To date the wall looks good and has performed well, with only minor face deformation. With the rigid panels and the lightweight variable backfill material used, the minor face deformation has caused some offset and cracking of a couple panel corners.

Case History 6

Site: Little North Fork, Plumas National Forest, Oroville, California: Date constructed: 1989, Wall type: 1:1 reinforced fill plus welded wire toe wall, Fill height: 15.2 m (50 ft), Wall height: 3.2 m (10.5 ft).

The backfill material is local fine silty sand (SM) to a sandy silt (ML) with up to 55 percent fines and a PI of 3. The soil is derived from weathered metamorphic rock. Specified compaction was 95 percent of AASHTO T-99.

This steep slide area and road repair was investigated and evaluated for a retaining wall but had marginal foundation materials and an unsafe excavation back slope. It was also marginally steep to support a 1:1 fill. Thus a small welded wire retaining wall was custom designed and placed on a firm bedrock area to support the toe of the reinforced fill. A geogrid reinforced fill was designed and constructed above the wall.

To date the composite structure has performed well, with little wall settlement and with good vegetative growth on the fill face except for several local shallow fill face slumps between the layers of secondary reinforcement. The geocomposite drainage system under the fill continues to function, discharging a moderate flow of water.

Case History 7

Site: Thomjack, Klamath National Forest, Yreka, California: Date constructed: 1989, Wall type: timber-faced geogrid wall, Wall height: 4.6 m (15 ft).

The backfill material is a nonplastic silty sand with gravel (SM) and up to 27 percent fines.

A timber-faced structure was chosen to satisfy a natural, aesthetic appearance for this forest road. The wall was custom designed, using a biaxial geogrid for reinforcement and 20- by 20-cm (8- by 8-in.) treated timbers, set on a 1:32 batter. Timbers are connected to the geogrid with staples or the geogrid is sandwiched between the timbers.

To date there has been no visible settlement and overall performance has been excellent. Its rustic appearance is pleasing. No appreciable volume of backfill has been lost through the partially open face.

SUMMARY AND CONCLUSIONS

Hundreds of MSB structures, with a wide variety of construction and facing materials, using local materials have been successfully constructed on Forest Service roads in rural areas over the past 20 years.

Welded wire walls and geotextile or geogrid-reinforced soil walls with various facing materials (such as timbers, gabions, tires, geocells, or segmental concrete blocks) appear ideal for rural applications on low- to moderate-volume roads. Reinforced fills can offer an economical alternative to conventional retaining structures. These structures represent the low range of costs for retaining structures available today and are appropriate in many settings. Substantial cost savings can be realized by their use, not only for the federal government, but also for state transportation agencies, counties, and the private sector.

Use of in-house geotechnical skills is cost effective for projects involving retaining structures. For actual structural design, either a custom design or a standard design provided by vendors may be suitable. However, to evaluate the most applicable type of structure, to perform site evaluation and foundation assessment, to evaluate design and construction modifications, and to perform needed external and global stability analysis (typically not provided by vendors), timely input from qualified geotechnical personnel is necessary.

Finally, significant additional cost savings can be realized by using local, typically on-site backfill material. Its use by the Forest Service has been satisfactory. However, use of marginal materials introduces the need for positive drainage, some additional construction effort, and allowance for some settlement or overall deformation. In most noncritical applications, these factors are acceptable and economical. Use of marginal materials will likely become more widely accepted.

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