Stabilization of Debris Flow Scar Using Soil Bioengineering

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On January 4, 1982, a large debris flow occurred in an undeveloped hillside and flowed into an area of residential housing in Pacifica, California. This debris flow (which originated in a previously unrecognized colluvium-filled swale) destroyed two houses approximately 300 vertical-ft below the source area and killed three children. Emergency grading and erosion control measures were soon implemented but these measures did not stop the continuing erosion. Deterioration of the temporary erosion control facilities was rapid. The magnitude of erosion from the slope also prevented vegetation from being reestablished in the scar area. In March 1988, plans were developed to regrade the source area of the debris flow (to remove additional colluvium) and install long-term soil bioengineering erosion control measures. These measures were designed to immediately reduce surficial erosion. A reduction in the surface water flow rate would allow increased infiltration into the ground and help rapid root growth of the bioengineering materials to allow root reinforcement of the upper soils. Over several years, this system would reduce the surficial erosion and allow indigenous plants in the area to become reestablished in the debris flow track. Design concepts and methods of construction are related. A long-term monitoring program is being performed by the consultants originally involved in the project to determine the success of the stabilization effort. This program consists of periodic visits to the site to walk the slopes and develop a photographic log of the vegetation development.

During an intense rainstorm on the evening of January 4, 1982, a large debris flow occurred in an undeveloped hillside and flowed into an area of residential housing in Pacifica, California (Figure 1). The debris flow happened with little or no warning to the residents some 300 vertical-ft below the source area. Approximately 3000 yd^3 of colluvium were mobilized in the flow. The colluvium mobilized by the failure moved rapidly down the slope at an estimated speed in excess of 20 mph. Three children were killed, two homes completely destroyed, and two other homes severely damaged when the mobilized soils hit them. The source area was approximately 150 ft long and 80 ft wide, and the track was about 460 ft long and 40 ft wide.

Immediately after the debris flow event, emergency remedial measures were taken to minimize the potential (in the short term) of another debris flow in the same area. After temporary emergency remedial measures were taken, numerous investigations were carried out. These investigations generally concluded that the debris flow occurred along the centerline of a colluvium-filled bedrock hollow. Depth-to-bedrock contours within the flow developed by Shlemon (*1*) indicated the presence of two deep depressions in the bedrock aligned in the downslope direction (see Figure 2). Theories stated that these depressions were caused by past episodes of fluvial downcutting, the high point between the two depressions being a more resistant bedrock material.

Generally, it was concluded that the upper depression in the bedrock was the source area for the flow. The high bedrock ridge that separated the two bedrock depressions acted to concentrate groundwater in the upper basin until the overlying colluvium became saturated and mobilized in the form of a debris flow. The flow material crossed the lower depression en route to the level, developed areas at the base of the slope.

The land where the debris flow originated was open space owned by an adjacent condominium homeowners' association. This group wanted to institute remedial work of the flow area, but its budget was limited. Engineering analyses of the slope led to the development of two alternative remedial plans. One plan involved the complete reconstruction of the slope to the pre–debris flow configuration. To achieve this, up to 5000 yd^3 of fill would have to be brought in and placed in the source area. In addition, to reestablish the original inclination of the slope, geogrid reinforcement of the soil would have to be added as the fill was placed. The alternative plan was to accept the existing conditions and install protective measures to minimize the likelihood of future debris flows and surficial erosion. To minimize the risk of future debris flows emanating from the existing source area, it would be necessary to remove most of the colluvial soil from both the center and the denuded flanks. Once this removal had taken place, stabilization measures could be installed to minimize future erosion, shallow sloughing, or small debris flow initiation. It was decided that an appropriate form of stabilization would involve the installation of soil bioengineering measures. Soil bioengineering slope stabilization involves the use of both quasivegetative and vegetative elements to arrest and protect against shallow slope failures and erosion.

Ultimately, the second alternative was selected and detailed plans were developed. The selection was based on both the cost of design and the feasibility of construction. A situation in which soil bioengineering slope stabilization was used to minimize soil loss from a large debris flow scar and a report on the performance of soil bioengineering to date are presented.

PREVIOUS TEMPORARY REMEDIAL OPERATIONS

After the debris flow occurred, emergency grading operations started to remove a portion of the remaining colluvium around

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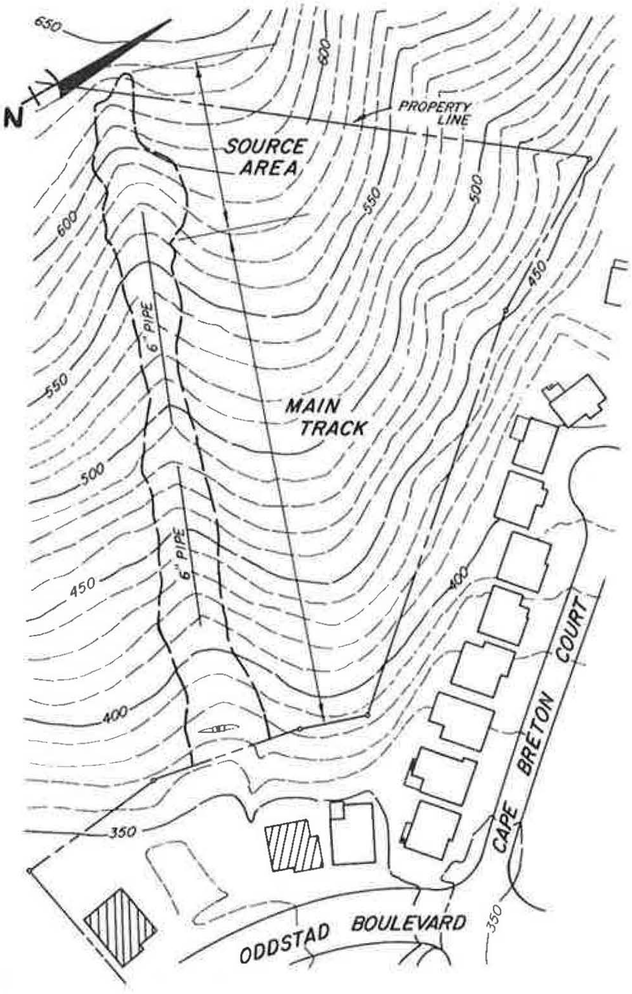

FIGURE 1 Oddstad Boulevard debris flow; two destroyed homes have been removed, and shading indicates severely damaged homes.

the perimeter of the source area. The limits of the grading extended beyond the limits of the source area to help reduce the inclination of the flanks of the slide while minimum earth movement was being done in the track area where the disturbance was small during the debris flow event. During these grading operations several thousand cubic yards of colluvium were removed from the source area. On completion of the grading, the source area had the configuration of a broad bowl, and the track area was essentially unchanged. V-ditches, debris baffles, and silt fences were constructed in the flowtrack. A siltation basin designed to contain erosion and small debris flows was also constructed at the bottom of the hill where the two residences had once stood.

By the fall of 1983 the temporary remedial operations had been completed, and the slope was seeded and left alone in hopes that vegetation would become reestablished in the giant scar that was left behind by the debris flow and the earthmoving operations. However, little vegetation was established on the slope that year because the inorganic soils that had been left behind did not promote plant growth and the steep inclination of the slope encouraged erosion of the surficial soils. The homeowners' association made many attempts to minimize erosion of the surficial soils exposed on the slope and increase the plant population by planting various types of grass seed. These additional plantings did not do much to increase the number of plants on the slope and reduce erosion.

By late 1985 erosion in the debris flow scar had become severe. A gully approximately 5 ft deep had been incised into the centerline of the flowtrack and more uniform, shallow, surface erosion over the remainder of the graded area led to large quantities of soil being deposited in the v-ditches and behind the silt fences. This accumulation of eroding soils required constant maintenance by the homeowners' association in order to keep the features operating. However, even with constant maintenance, deterioration of the temporary erosion control facilities was rapid. The silt fences had almost completely overloaded and broken down, and the siltation basin at the base of the slope had been substantially filled.

LONG-TERM REMEDIAL PLAN DEVELOPMENT

In 1986 a long-term solution to the slope stability and erosion problems was being sought. Investigations of the initial debris flow event led to the belief that accumulation of groundwater in a bedrock hollow near the top of the hillside during prolonged or intense rainstorms would saturate the colluvial soils in the hollow. During an intense rainstorm on January 4, 1982, the colluvium became saturated and ultimately liquefied and flowed down the slope in the form of a debris flow. An investigation by Shlemon (*1*) established depth-to-bedrock contours in the debris flow area. These contours outlined two bedrock hollows on the hillside that were aligned in the downslope direction. Consultants spot-checked these estimated depths to bedrock by drilling exploratory test borings. Many of the borings were extended to the bedrock surface and terminated, several others were advanced into the bedrock by coring. The deeper borings were drilled in an effort to examined the type and quality of the underlying materials. The borings generally confirmed the depth-to-bedrock contours developed by Shlemon (*1*).

Once the contours were verified, it became apparent that the emergency grading measures had not removed the entire build-up of colluvial soils from the upper bedrock hollow. This kindled fears that additional debris flow activity might occur during similar rainstorm events. A decision was made to remove the colluvium in the central portion of the bedrock hollow to within 3 to 5 ft of the bedrock surface. The remaining thickness of colluvium could then be adequately stabilized in-place through the use of soil bioengineering methods. Draining of groundwater from the source area was also considered a prime objective of the remedial measures. Ultimately, it was demonstrated that the removal of colluvium from the central portion of the bedrock hollow in combination with the installation of subsurface drainage and construction of soil bioengineering stabilization measures would provide adequate protection against future flow events.

The depth-to-bedrock contours developed by Shlemon indicated that the horizontal extent of the bedrock hollow was significantly larger than that of the debris flow source area. Therefore, the extent of additional colluvium removal had to

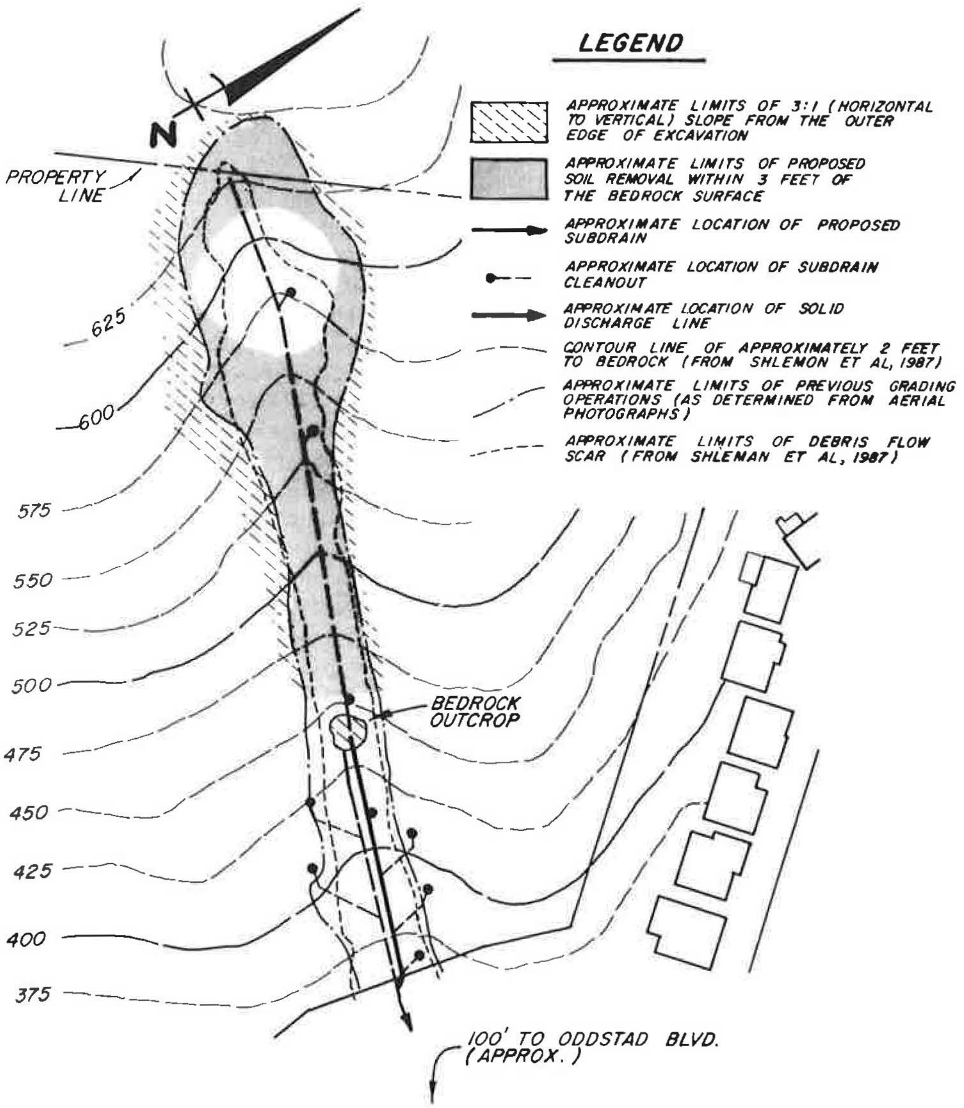

FIGURE 2 Depth-to-bedrock contours in relation to debris flow.

be determined. The central portion of the source area appeared to be immediately above the deepest portion of the bedrock hollow and a substantial thickness of colluvium still appeared to be present under the flanks of the debris flow. It was decided colluvium would be removed within the central portion of the bedrock hollow down to within 3 to 5 ft of the bedrock surface. This removal would generate approximately 5000 yd^3 of colluvium to be removed during the grading operations in the source area.

A subdrain, designed to relieve build-up of hydrostatic pressures, was to be constructed down the centerline of the source area (Figure 3). Because previous investigators had theorized that a perched groundwater table may exist during heavy or extended periods of rain on the bedrock surface, the subdrain was to be excavated through the remaining colluvium and approximately 1 ft into the underlying bedrock. The subdrain was to consist of a 6-in. rigid, perforated, plastic pipe embedded in washed gravel. The gravel was to be extended to within 1 ft of the ground surface and the entire gravel-pipe unit was to be wrapped in a nonwoven geotextile. Natural soils were to be placed above the gravel and geotextile.

In order to excavate down to within 3 to 5 ft of the bedrock surface along the flanks of the source area, it would be necessary to remove a significant amount of existing, well-established vegetation and to disturb vast areas of previously undisturbed ground. Because a subdrain was to be constructed through the central portion of the bedrock hollow, it would be unlikely that the colluvium in the flanks could become saturated and mobilize into a debris flow. Therefore, the two primary concerns for the flanks of the graded area were local slope stability and surficial erosion. The grading operations proposed for the central portion of the source area would oversteepen the flanks and make them susceptible to localized sloughing and slope failures.

To minimize the likelihood of such failures, it was recommended that the flanks of the source area be cut back to a maximum inclination of 3:1 (horizontal to vertical). This cutting-back operation would minimally affect the existing dense vegetative cover outside the source area (see Figure 3). Therefore, the area susceptible to surficial erosion would only be slightly increased by the recommendations for the grading scheme. Once the flanks were cut back, soil bioengineering slope stabilization measures would be installed to minimize erosion from the slopes and provide root reinforcement of the surficial soils.

SOIL BIOENGINEERING SLOPE STABILIZATION

Soil bioengineering slope stabilization entails the use of vegetative elements to arrest and minimize the potential for slope failures and erosion (*2*). These vegetative elements include seeding, live transplants, and quasivegetative methods such as brush layers and contour facines (wattling).

Bioengineering is different from biotechnical engineering in that biotechnical engineering includes the use of mechanical elements such as small walls and earth reinforcing. The mechanical elements of biotechnical engineering provide relatively deep soil stabilization; bioengineering measures provide stabilization of surficial soils. Soil bioengineering also acts to reduce the erosive power of surface water by directly intercepting rainfall, binding soil particles, filtering soil from runoff, dissipating the energy of runoff, and maintaining good infiltration. In addition, woody plants, trees and shrubs provide root reinforcement to depths of 3 to 5 ft, which adds to the general stability against sliding and mass movement. Once stabilization and erosion control are achieved, indigenous vegetation may then reestablish itself. The ultimate goals of soil bioengineering stabilization are to provide relatively shallow slope stabilization and to inhibit the erosive action of surficial water long enough to allow the imported and indigenous plant materials to establish a vegetated mat over the ground surface.

It should be noted that soil bioengineering methods of slope stabilization are only slowly gaining popularity in North America. Generally, these methods are used in areas of relatively constant soil moisture such as along stream banks or where groundwater is at a constant, shallow depth. The subject debris flow is located along the flank of a small mountain in the California coast range in an area where the depth to groundwater is typically greater than 20 ft. In addition, even though the area typically receives more than 22 in. of rainfall each year, it is seasonal in nature. The rainy season usually lasts from mid-October to April, and rainfall during the remainder of the year is rare. Nevertheless, it was concluded that with proper timing and plant selection, soil bioengineering methods would be effective in terms of both cost and results in controlling erosion from the debris flow scar.

To minimize the likelihood of future mass failures in the debris flow source area, it was decided that additional grading that involved the removal of existing colluvial soils from both the flanks and bottom of the basin would be performed. The proposed grading operations would remove all but 3 to 5 ft of soil from the debris flow scar, so the engineering consultants, in conjunction with the landscape architect, decided that the primary function of the soil bioengineering stabilization effort were to minimize erosion of the surficial soils so that plant life could become reestablished on the slope and to provide mechanical stabilization of the surficial soils during the interim when vegetation was becoming established. The three soil bioengineering stabilization processes chosen to

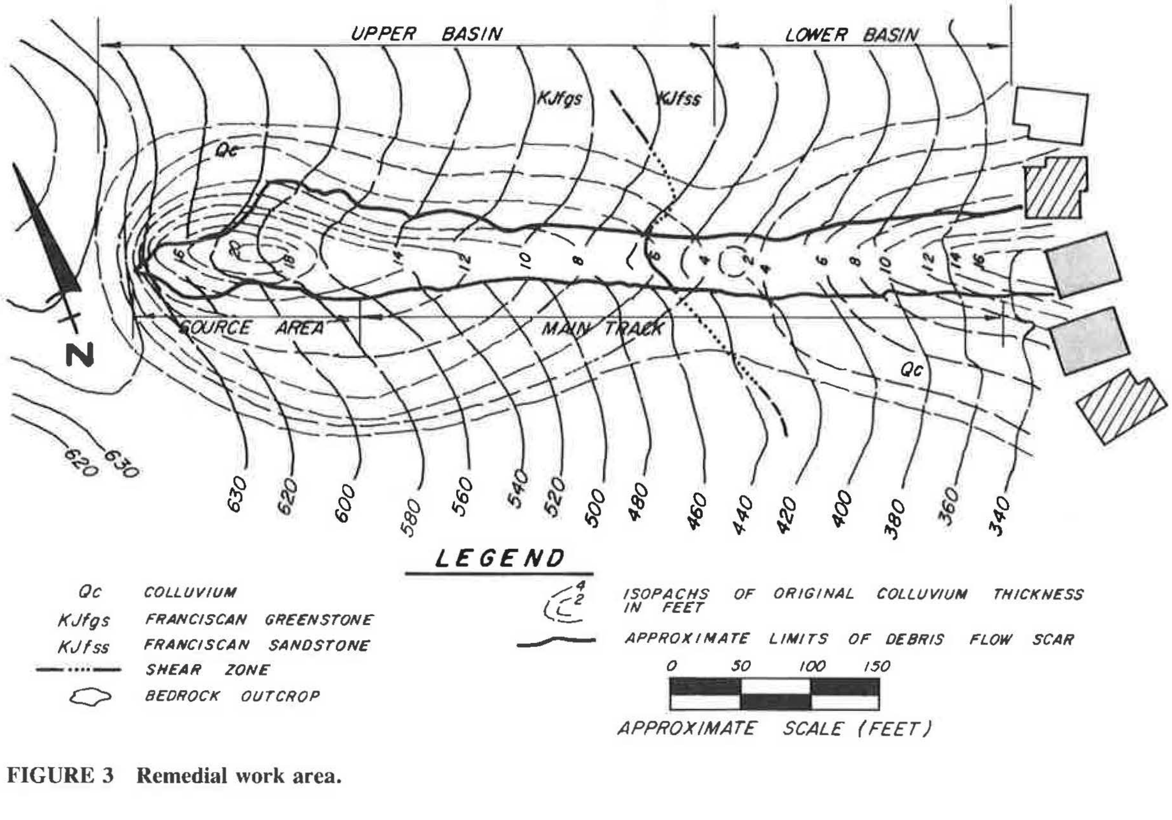

FIGURE 3 Remedial work area.

accomplish this goal were contour facines, live transplants, and seeding. The contour facines were to provide mechanical stabilization that would allow the transplants and seeds to become established on the slope.

Because soil bioengineering slope stabilization is not commonly used throughout North America, brief descriptions of the methods used for the subject stabilization are presented. For additional information about these and other soil bioengineering stabilization methods, refer to the text by Gray and Leiser (*2*).

Facines (Contour Wattling)

Facine construction consists of placing bundles, approximately 12 in. in diameter, of suitable plant materials (generally quick rooting woody vegetation that is in abundant supply) in shallow trenches, on contour, and on either cut or fill slopes (*2*). The function of the facine is to stabilize the surficial soil layers, dissipate the erosive power of surficial water, entrap sediments, and increase infiltration of surficial water. The proper construction and installation of facines is critical. Freshly cut stems should not be allowed to dry out or they will die and no rooting will occur. Death of the vegetation will not destroy the mechanical properties of the facine, but no new growth of vegetation will be supplied by the facine. Improper installation of the facine may also lead to unacceptable results. Failure to adequately cover the facine with soil may prevent the fresh stems from sprouting. In addition, failure to tightly pack soil around the facine may lead to ponding of surficial water in the trench around the facine, which often leads to shallow sloughing failures that extend beneath the facine.

In general, it was considered that within the debris flow scar, contour facines would provide immediate stabilization of the surficial soils so that additional vegetation could become established in the area. The ability of the facine to act as a check dam would increase infiltration of surface water while reducing erosion. It was considered that the facines would provide this type of protection for up to 3 years, and this would allow both imported and indigenous vegetation to become established in the scar and take over those functions.

Live Transplants

Use of transplants is one of the best methods of establishing woody vegetation on difficult sites. The advantage of transplants is that the plants do not have to undergo germination in the typically harse site conditions, therefore giving them a distinct advantage over seeding of woody vegetation. In addition, the survival rate of transplanted woody vegetation is significantly higher than that of seeded woody vegetation. However, the cost of transplants is greater than seed because they have to be grown and then planted at the site by hand. Transplanting should be restricted to seasons in which adequate moisture is available in the soil; otherwise, irrigation may be necessary. As live transplants become established, they reduce erosion of surficial soils by intercepting rainfall in their vegetative canopy, increasing infiltration of surficial water into the soil, and increasing the quantity of organic debris on the ground surface, which retains moisture. In addition, the roots of woody plants reinforce the surficial soils, which increases slope stability.

Of the three types of soil bioengineering stabilization selected for this site, live transplants have the longest potential life span. The woody vegetation that makes up the majority of live transplants has the potential to survive on the slope anywhere between 10 and 80 years or more, at which time natural succession would take over.

Seeding

Seeding for herbaceous plants provides the most immediate form of ground cover. Once the seeds have germinated, plants rapidly develop and act to minimize surficial erosion, provided that rill and gully erosion is minimized during this time through other methods such as contour facining. The ideal species should have strong root development and minimal green growth (*2*). The green growth that does occur will help minimize the impact of raindrops on the slope, and the root development will reinforce the surficial soils. Ground cover established through seeding minimizes surficial erosion while the live transplants become established. Once transplants have become established on a slope, their roots provide deeper soil reinforcement. Providing an adequate mix of grass and herbaceous plant types is of particular concern when specifying seeding. Some grasses are quick to develop but are only short-lived, and therefore only provide immediate protection; other grasses take much longer to develop and spread but provide more long-term erosion protection. Another concern is selecting a mix of both annual and perennial vegetation so that more than one season of protection may be obtained. However, even with a good selection of species, seeded plants generally provide 2 to 5 years of slope protection.

SOIL BIOENGINEERING PLAN DEVELOPMENT

Factors Affecting Plant Selection

Exploratory borings that were drilled as part of the geotechnical engineering investigation generally encountered stiff, inorganic, sandy, and gravelly clays immediately above the bedrock surface. This soil was expected to support and sustain the plant materials used in the soil bioengineering stabilization program. In general, stiff clayey soils that are exposed at the surface retain moisture and nutrients well. However, these soils had been buried for an extended period of time, so it was unlikely that they contained many nutrients. In addition, it was likely that the denseness of these soils would cause them to lack oxygen, which is vital to plant development. During initial site inspections, sparse vegetation, apparently introduced to the area during the temporary remedial measures, was noted within the debris flow source and track areas. This vegetation consisted of the hardy *Rhamnus* and *Baccharis* species. Growth was observed to be nonuniform and the plants appeared to be small for their age. This was reflective of the severe environmental conditions and the nutrient deficient soils.

Climatic conditions at the site also played a major role in the development of the soil bioengineering stabilization plan.

These conditions presented both positive and negative factors that could affect plant selections and expected growth rates. In relation to the rest of the San Francisco Bay Area, the site is located in an area that receives relatively generous rainfall. On the average, the Pacifica area receives about 22 in. of rainfall per year. However, most of it occurs between mid–October and mid–April. The rest of the year is dry except for an occasional rainshower in May or September. Because the site is located within 2.5 mi of the Pacific Ocean, seasonal temperature variations are not extreme. Typically, during the winter months, temperatures at night drop as low as 40 degrees; summer daytime temperatures rarely exceed 75 degrees. Often during the summer, coastal fog blankets the hillsides, which creates a cool, humid environment for plants but does little to replenish soil moisture.

The lack of summer moisture in this area dictates that the plants growing here be tolerant of drought conditions. Typically, such plants do not grow throughout the season. The rainfall and temperature characteristics also dictate that in nonirrigated areas, plantings be scheduled during the wet winter months and not in the dry spring or summer months.

Plant Selection

Budgetary constraints imposed by the homeowners' association did not allow extensive testing of the soils in the debris flow track. Such testing would have aided in plant selection by determining nutrient levels, soil pH, salinity, and the presence of potentially toxic ions such as those produced by serpentine bedrock. To compensate for this lack of laboratory data, an extensive plant survey was conducted on the adjacent slopes. The purpose of this was to determine the plant types and populations on the adjacent slopes in order that similar species could be selected for the soil bioengineering stabilization plan. A list of the plant types noted during this survey is presented in Table 1.

TABLE 1 SURVEY OF EXISTING PLANT MATERIALS

Debris Flow Source and Track Areas*	Undisturbed Adjacent Slopes***
**Baccharis species (Coyote Brush)	Salvia species (Sage)
**Rhamnus californica (Coffeeberry)	Mentha species (Mint)
	Ceanothus species (Wild Lilac)
	Ribes species (Gooseberry)
	Sambucus (Elderberry)
	Rhamnus species (Coffeeberry)
	Baccharis species (Coyote Brush)
	Rhus diversiloba (Poison Oak)
	Heteromeles arbutifolia (Toyon)
	Pinus radiata (Monterey Pine)
	Cornus species (Dogwood)
	Salix species (Willow)

* The slide path contained a scant mixture of grasses

** These plants were sparse and small for their age

*** Undisturbed areas contained dense growth of grasses as well as the indicated plants

Often, texts describing soil bioengineering stabilization strongly recommend that only indigenous plants be used for stabilization efforts. They suggest that local seed be collected and used in reestablishing vegetation to ensure compatibility of the remedial work area with the surrounding areas. It is also thought that, in general, species that thrive in an area do so because they are best suited for the soil and climatic conditions. However, it was decided that additional plant types may also thrive on the slope. The genera of the plants noted during the plant survey were used as to indicate the types of plant materials that would thrive in this type of environment. The criteria used in selection of the plant materials for transplants and seeding of the debris flow area were that the plants be well adapted for the expected soils and moisture conditions, deep rooting, tenacious and hardy, commercially available, and highly adaptable to varying climatic conditions. On the basis of these criteria, a list of acceptable plants from which contractors could select was prepared (Figure 4).

Contour facines were selected to provide immediate vegetative and mechanical stabilization of the surficial soils. The plant material selected to create the facine would have to be strong, resilient, quick rooting, and in abundant supply. Because the primary function of the facine is to provide immediate surficial soil stabilization and erosion control while indigenous and transplanted vegetation becomes established on the slope, its required life span is only 1 to 3 years. Therefore, selection of a plant type with the proper mechanical properties is more important than selecting a plant that will have a long-term survival rate on the slope. Willow is abundant along the stream banks and possesses the required mechanical properties, so

Transplant list

Artemisia california (Sagebrush)
A. suksdorfii (Sagebrush)
Baccharis pilularis subs. pilularis
Ceanothus cuneatus (Wild Lilac)
C. incanus (Wild Lilac)
C. intergerrimus (Wild Lilac)
C. papillosus (Wild Lilac)
C. parryi (Wild Lilac)
C. ramulosis (Wild Lilac)
C. thyrsiflorus (Wild Lilac)
Cornus glabrata (Dogwood)
Cupressus macrocarpa (Monterey Cypress)
Fremontodendron california (Flannel Bush)
Heteromeles arbutifolia (Toyon)
Pinus radiata (Monterey Pine)
Rhamnus california (California Coffeeberry)
R. crocea (Redberry)
Rhus integrifolia (Lemonade Berry)
R. laurina (Laurel Sumac)
Salvia apiana (White Sage)
S. columbariae (Chia)
S. leucophylla (purple Sage)
S. mellifera (Black Sage)
S. sonomensis (Creeping Sage)
Sambucus callicarpa (Elderberry)

Seed Mixture

Berber orchardgrass (20 lbs./acre)
Crimson Clover (3 lbs./acre)
Wilton Rose Clover (10 lbs./acre)
California Poppy (1 lb./acre)
Blando Brome (10 lbs./acre)
Annual Rye (5 lbs./acre)

FIGURE 4 Recommended transplant list and seed mixture.

it was selected for use as facine material. However, because willow adapts to wet environments and summers at the site are typically drought periods, its expected survival time on the slope is not much greater than 1 to 2 years.

GRADING AND INSTALLATION OF BIOENGINEERING MEASURES

In August 1989 grading operations began in the debris flow scar. During these operations approximately 5000 yd^3 of colluvial soils were removed from the center and flanks of the source area. Upon completion of the excavation operations, the grading contractor was instructed to rip the remaining soil to a depth of 18 in. to provide a more suitable medium in which the plants could become established. A subdrain was then installed from the center of the source area down the slope to the lowest v-ditch in the track area. During excavation of the subdrain, pockets of water were encountered and drained within several days of their exposure. The grading and subdrain installation operations were generally completed by the end of October.

Installation of the soil bioengineering measures commenced in mid-November. Several light rains had occurred during the period between the completion of grading and the commencement of installating the bioengineering measures. These rains dampened the ripped soils but were not intense enough to cause substantial erosion.

The landscaping contractor charged with the installation of the bioengineering measures obtained willow for the facines from a natural source in the southern part of California. The willow stems were cut in the morning, trucked to the site (a drive of about 5 hr) in late afternoon, bundled into facines, and placed the following day. The assembly of the facines was performed at the top of the hillside and the completed facines were conveyed down the slope to the installation area by a wireline assembly rigged by the contractor. The live transplants were obtained from a local nursery and arrived at the site within several days of planting.

The contractor's first objective was to install the facines in the debris flow area. The facines were placed on contour at a vertical spacing of about 6 ft. This spacing was determined by the inclination of the slope and the type of soil to be stabilized. In practice, this is a common facine spacing. Installation of the facines progressed from the top of the debris flow scar toward the bottom. By the Thanksgiving weekend, approximately the top quarter of the source area had been covered with the facines, which were placed on contour. A storm which produced approximately 2 in. of rain in a 12-hr period occurred over the weekend, causing substantial erosion from the untreated portion of the slope. Very little erosion was noted on the upper portion of the slope where the facines had been installed the previous week. During the following days approximately 20 yd^3 of eroded soils were removed from the v-ditches on the slope and the siltation basin at the base of the track area. In the lower portion of the source area runoff from the rains had created a gully approximately 2 ft deep. This gully was repaired by backfilling with lightly compacted soil and with the placement of a brush mattress, which was intended to reduce the erosive action of surface runoff. By mid-December the remainder of the facines and approximately 3,000 live transplants were installed and the area hydroseeded without further severe rainfall incidents.

After completion of the bioengineering planting there was a period of approximately 6 weeks where little or no rain fell. During this critical time for all of the plantings the slope was irrigated with a spray from a hydroseed machine. Although this method of irrigation was expensive, it appeared that most of the plantings survived the period of drought. The remainder of the winter was drier than usual; however, there was sufficient rainfall to allow the transplants to survive and the seeds to sprout. Little of the willow in the facines sprouted and grew; however, the mechanical properties of the facines did not appear to be compromised. During the few heavy rainfalls that occurred that winter, some erosion was observed in the source area. However, the facines acted to intercept the eroded material much as a silt fence would; therefore, little soil washed off the slope and gullies did not have an opportunity to form.

By the spring of 1990 the seeds had sprouted and a thick mat of grass and weeds covered the slope. Many of the live transplants were also thriving; however, deer in the area were aware of this recently transplanted vegetation and feasted on the young plants. This browsing by the deer population reduced the number of surviving transplants by at least 50 percent. During summers in this area very little vegetation grows. The plants that survived the first winter and the browsing of the deer also survived the first summer on the slope. The grasses and weeds went to seed, and the following winter a new crop sprouted. During a visit to the site in the spring of 1991, it was noted that native vegetation species from the area were beginning to encroach into the debris flow area. These species included sagebrush, toyon, and poison oak. None of the willow facines had survived, but they were still intact and functioning as vegetative silt fences. In addition, some of the live transplants had survived. These species included Monterey cypress, Monterey pine, coffeeberry, lemonade berry, and elderberry. It appeared that the Monterey pines had the greatest survival rate, and many of these trees ranged in height from 24 to 48 in.

The original specifications for the bioengineering recommended a 20 percent second planting of the live transplants 1 year after the initial planting. The condominium homeowners' association did not want to incur this additional expense and therefore did not authorize the second planting. Despite this, it appears the debris flow scar has stabilized and native vegetation from the surrounding hillsides is invading the area. Therefore, this project to date is considered a success.

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