throughout much of California.

Caltrans has more than 6000 acres of iceplant growing along California state highways. Iceplant was chosen as a ground cover because of its ability to grow well under poor soil conditions, its relatively low maintenance costs, and its adaptability to both cool coast and hot interior California growing conditions.

The Pulvinaria scale is so serious that the infestation threatens the survival of iceplants and possibly other succulent plants as well. Researchers have introduced a number of parasites and predators of these Pulvinaria scales from a search that was made in Africa and in southern Europe. These parasites and predators have been processed through quarantine facilities and have been released on infestations of Pulvinaria scale on roadsides in many areas of California.

Caltrans' involvement in research to reduce pesticide use and also to reduce the cost of roadside care has not been limited to insect pests. Caltrans has funded, with participation from FHWA, a number of research projects on the control of pest weeds. Most troublesome weeds on California's roadsides are introduced species, such as Russian thistle or tumbleweed (Salsola kali), puncture vine (Tribulus terrestris), field bindweed (Convolvulus arvensis), and yellow star thistle (Centaurea solstitialis).

About 20 years ago Caltrans watched with great interest the research work that was done with the importation of a beetle to control Klamath weed (Hypericum perforatum), a weed pest that had made thousands of acres of California agricultural land unfit for any productive use. Chemical control was tried and was found to be economically impossible. Several years after the release of these beetles only scattered stands of Klamath weed could be found. This example of biological control is an outstanding success, and these thousands of acres of previously infested land have been returned to the production of economic crops.

In 1960, host-specific insects were released on puncture vine in California. Caltrans has funded a research project with the USDA Biological Control of Weeds Laboratory, Albany, California, to collect and transfer the insects, to import different insects, and to explore the availability of pathogens against this weed pest. [A copy of the final report on the use of weed-feeding insects for the nonchemical management of puncture vine along California highways is available through the National Technical Information Service, Springfield, Virginia (number 282541) or by request to Caltrans.]

Caltrans has also funded a research project with USDA in Albany, California, to control Russian thistle by the use of imported moths. It is interesting to note that, until several years ago, Caltrans had been spending more than $1 million a year attempting to control and clean up this weed pest. Populations of this weed pest have been noticeably reduced, and the cost of control has been reduced greatly. Caltrans believes this to be at least partly due to the beneficial insects.

Caltrans is convinced of the desirability of spending money on research studies for the development of balanced systems that do not have the disruptive effects on the environment that has marked the widespread use of pesticides.

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Abridgment

Nylon Erosion-Control Mat

GARY L. HOFFMAN AND ROBERT ADAMSKY

The Pennsylvania Department of Transportation (PennDOT) has placed, and continues to place, emphasis on value engineering—the use of alternative cost-effective materials or procedures to perform a common function. As a result of this emphasis, a nylon erosion-control mat was recently field tested as a ditch lining on a project that was originally designed for rip-rap or paved-concrete lining. This nylon mat, installed with either a bituminous or wood cellulose surface treatment, provided a functional and economic erosion-control measure. In the trapezoidal ditches calculated, nonvegetated velocities were as high as 20 ft/s and vegetated velocities were as high as 8 ft/s. The mat installation resulted in a 60-70 percent cost saving over the rip-rap or paved-concrete lining alternatives. PennDOT has included this nylon mat in its general specifications as a result of the positive findings on this project. A significant benefit of this stabilizing fabric was the structural integrity it provided to the vegetation root system. The use of the nylon mat instead of the rip-rap or paved-concrete alternatives also resulted in slower final velocities and lower flow concentrations.

The Pennsylvania Department of Transportation's (PennDOT's) Design Manual provided for the use of erosion-control lining made of sod, jute matting, rock, gabions, or paved concrete, depending on anticipated velocities. The use of the last items, where higher velocities were expected, added substantial cost to the project.

Prompted by PennDOT's value engineering emphasis and by reports (1-3) of successful uses of the nylon mat by a few other state highway departments, a substitution of the nylon erosion-control mat for the designed rip-rap or paved-concrete lining was proposed. The substitution was allowed on two ditches with the stipulation that a formal research project, funded in combination by the Federal Highway Administration (FHWA) and the state, be initiated to evaluate the performance of the nylon mat. A final report (4), which this paper summarizes, was prepared by PennDOT as required by the research program.

INSTALLATION

The nylon mat was substituted for the rip-rap or concrete lining on two sections of trapezoidal ditches on the Monongahela Valley Expressway (Legislative Route 1125) in Washington County in the southwestern part of the state. The nylon mat was a flexible soil-reinforcement matting made from nylon monofilaments that are fused at the intersections (see Figure 1). It was a bulky mat, and its three-dimensional structure (about 0.75 in thick) allowed 90 percent of its volume to be filled with soil, gravel, or other appropriate material.

The first section was by the bituminous surface method and was placed on July 18 and 19, 1979. The trapezoidal ditch had a bottom width of 2 ft, side slopes of 1.5 on 1.0, and a depth of 3 ft. This

Figure 1. Close-up view of nylon mat.

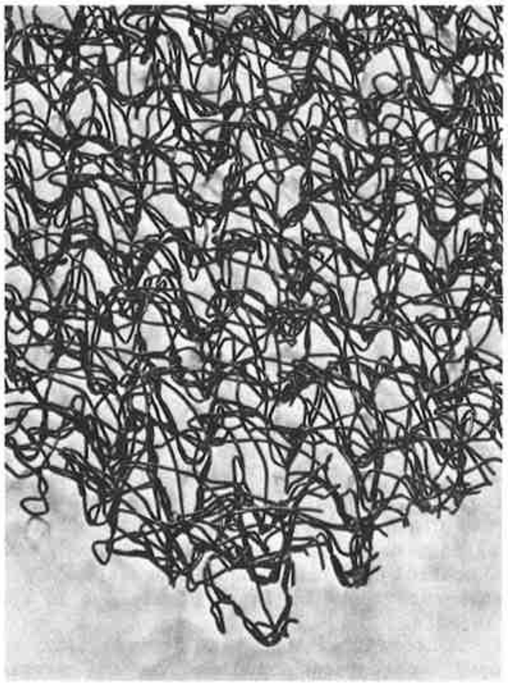


Figure 2. Construction details.

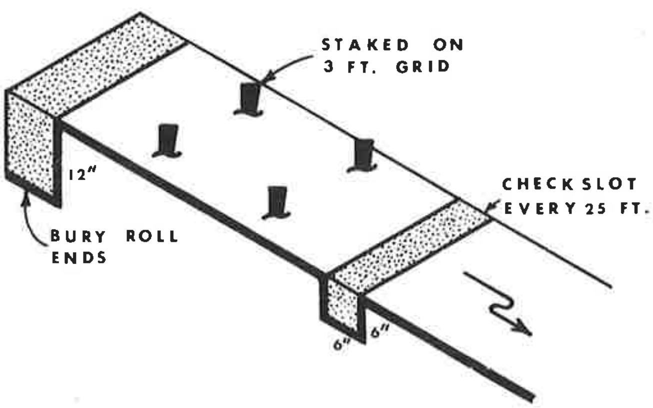
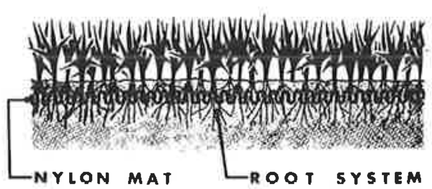


Figure 3. Schematic of integral mat and root system.



wet-bottom ditch had an average slope of 16.5 percent and carried the outfall from a 30-in-diameter corrugated metal pipe culvert. The outfall water was temporarily diverted during construction. First, a nonwoven geotextile was placed on the ditch bottom; then three strips of the nylon mat, one on the bottom and one on each of the two side slopes, were placed. Both the nylon mat and the geotextile were provided in 3-ft-wide rolls. After placing, staking, and trenching in accordance with the schematic shown in Figure 2, the seed (45 percent crown vetch and 55 percent ryegrass) and soil supplements were placed. A crushed slag aggregate--which had gradations of 0.50 in, 100 percent; 0.375 in, 95-100 percent; No. 8, 30 percent; and No. 100, 8 percent--was then broomed into the mat and tack-coated with 0.3-0.4 gal/ $yard^2$ of E-6 emulsified asphalt.

The second section was by the wood cellulose surface method and was placed on September 13, 1979. The ditch in this area had a cross section similar to that in the first section, had an average slope of 22.5 percent, and carried water from a paved-concrete slope interceptor ditch. Again, three strips of the nylon mat were placed in the trapezoidal ditch, and the manufacturer's recommended installation procedures shown in Figure 2 were followed. The nonwoven geotextile was not used in this section, since the ditch bottom was not continually wet. After placing the nylon mat, wood cellulose was hydrosprayed over the entire mat at the rate of 320 lb/1000 $yard^2$. Portions of this section were seeded and supplemented before spraying, and the other portions were seeded and supplemented simultaneously with the spraying operation.

PERFORMANCE DATA

Both sections of the nylon mat have performed well after two years in service. The crown vetch initially had established itself along both sides of the trapezoidal ditches and, for the most part, it now has encroached across the bottom of even the continually wet ditch. The nylon mat has become an integral part of and reinforcement to the vegetation root system, as claimed by the manufacturer (Figure 3).

Velocities were established from actual field measurements and from calculations by using Manning's formula for open channel flow. These velocities are listed below for the bituminous and wood-cellulose-treated sections:

1. Bituminous method velocities: vegetated (measured)--5 ft/s, gravel bottom (calculated)--9 ft/s, and concrete paved (calculated)--14 ft/s.
2. Wood cellulose method velocities: vegetated mat (calculated)--8 ft/s, nylon mat only (measured)--10 ft/s, and gravel bottom (calculated)--14 ft/s.

The measured velocity of 5 ft/s in the bituminous section was made about three months after construction when a full stand of ryegrass existed on the side slopes of the ditch. A roughness coefficient (n) of 0.05 was established for the measured velocity and flow conditions. This n value agreed well with published ranges. Published estimated n values of 0.03 for the unlined gravel bottom ditch and 0.012 for the paved-concrete lining were used to calculate the 9 ft/s and 14 ft/s in the wood-cellulose-treated section made shortly after construction when no vegetation or siltation was present on the mat. An n value of 0.04 was calculated for these measured hydraulic conditions. Velocities of 8 ft/s for the vegetated ditch and 14 ft/s for the unlined ditch were calculated by using the n values given above. If this section of ditch had been lined with paved concrete, a velocity in excess of 30 ft/s would have resulted for these hydraulic conditions. Detailed hydraulic calculations are provided in the previously mentioned research report (4).

The portions of the wood cellulose section that were seeded and supplemented simultaneously with the hydrospray operation developed a grass stand at the same rate as the portions that were seeded as a

Table 1. Cost breakdown for mat-lined sections.

Material and Installation	Cost[a] ($)
Bituminous Surface Method[b]	
Labor: 3 people at $7.46/h x 16 h	358
Equipment: hydroseeder, truck, and high lift	100
Nylon mat: 174 yard² at $3.42/yard²	595
Geotextile: 57 yard² at $0.63/yard²	36
Seeding: $0.07/yard² (Formula C)	20
Stone: 4 yard³ at $7.50/yard³	30
Asphalt emulsion: 60 gal at $0.58/gal	35
Stakes: 155 wooden at $0.11/stake	17
Total	1191
Wood Cellulose Method[c]	
Labor: 4 people at $7.46/h x 8 h	240
Equipment: hydroseeder, truck, and high lift	60
Nylon mat: 245 yard² at $3.42/yard²	838
Seeding: $0.07/yard² (Formula C)	17
Stakes: 228 wooden at $0.11/stake	25
Total	1180

[a] Cost data are given in rounded figures.
[b] Alternate methods of calculating for bituminous surface method: 146 yard² at $8.15/yard² or 155 linear ft at $7.68/linear ft.
[c] Alternate methods of calculating for wood cellulose method: 215 yard² at $5.50/yard² or 228 linear ft at $5.23/linear ft.

separate operation before hydrospraying. There was no difference in overall performance between these two sections.

The geotextile was used to prevent soil erosion under the mat when used in a continuously wet-bottom ditch. After several inspections over a period of time, it was determined that this fabric material provided additional protection under these conditions. There was some initial concern that the geotextile would retard vegetation growth. Although the fabric would retard germination and prevent growth if seed was placed below the geotextile, this nonwoven fabric did not prevent root penetration from the top down. This was evidenced by the crown vetch encroaching completely across the bottom of the ditch.

COST DATA

A substantial unit-cost saving was realized by using the nylon mat lining in lieu of paved-concrete or rip-rap lining. The original contract was bid at $19.30/linear ft of ditch for rip-rap, and the contractor was in favor of providing paved-concrete lining as an alternative at this same unit cost. These unit costs were high because of the relatively few sources of quality aggregates in the southwestern part of the state. The actual costs for the nylon mat with bituminous surface and wood cellulose methods were $7.68 and $5.23/linear ft of ditch, respectively. The itemized cost breakdown for the mat-lined sections are tabulated in Table 1.

A typical cost for a jute matting installation is $2.50/yard². However, jute matting is less effective and is only a temporary erosion-control measure. It would not be applicable in the same situations where the nylon mat could be used.

CONCLUSIONS

The nylon mat installed with both the bituminous surface and wood cellulose treatments provided an effective and economical erosion-control measure in ditches with initial nonvegetated velocities up to 14 ft/s and final vegetated velocities on the order of 8 ft/s. The mat installation resulted in a significant unit-cost savings over the rip-rap or paved-concrete lining alternatives on this relatively small experimental project. It is expected that unit costs for the installed mat may decrease on projects with larger quantities and when subcontractors become more familiar with this material and its installation techniques.

The use of the nylon mat in promoting vegetated ditches provided the advantages of groundwater recharge and additional lag time in runoff flow concentrations. By allowing more water to percolate back into the subsoil than a concrete-lined ditch, the vegetated mat-lined ditch reduced the total quantity of water discharged into the downstream water basin. Furthermore, by reducing the maximum velocity to about one-third of the velocity anticipated with a concrete-lined ditch, discharges were not concentrated as rapidly downstream. The need for energy dissipation was also lessened. The potential for undermining of the ditch lining, which is prevalent with paving or rip-rap, was minimized, since the mat provided structural integrity to the vegetation root system.

From the results of the experimental projects, the following items are recommended:

1. Specify nylon mat with either of the two surface treatments in PennDOT's general specifications as an alternative to rip-rap or paved-concrete ditch lining where calculated flows in the unlined trench do not exceed 10 ft/s;
2. Allow the application of seed, soil supplement, and wood cellulose mulch in a single operation;
3. Specify a wood cellulose mulch application rate of 640 lb/1000 yard² to provide better seed cover at only a 1 percent cost increase; and
4. Use longer wooden stakes (18 in) in check slots and terminal ends when soft subsoil material is encountered instead of the specified 12-in stakes.

ACKNOWLEDGMENT

The manufacturer's (American Enka Company, Enka, North Carolina) specifications for product #7020 were used for this work. C.S. Kemic, technical advisor for American Enka, provided assistance during the installation. Suburban Spray Service of Pittsburgh was the subcontractor that made the installation.

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