STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

EROSION CONTROL ON CALIFORNIA STATE HIGHWAYS

REPRINT OF A SERIES OF ARTICLES PUBLISHED IN
"CALIFORNIA HIGHWAYS AND PUBLIC WORKS"

RETURN TO
MASTER FILE
LANDSCAPE ARCHITECTURE

EARL WARREN
Governor

CHARLES H. PURCELL
Director of Public Works

GEORGE T. McCOY
State Highway Engineer

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

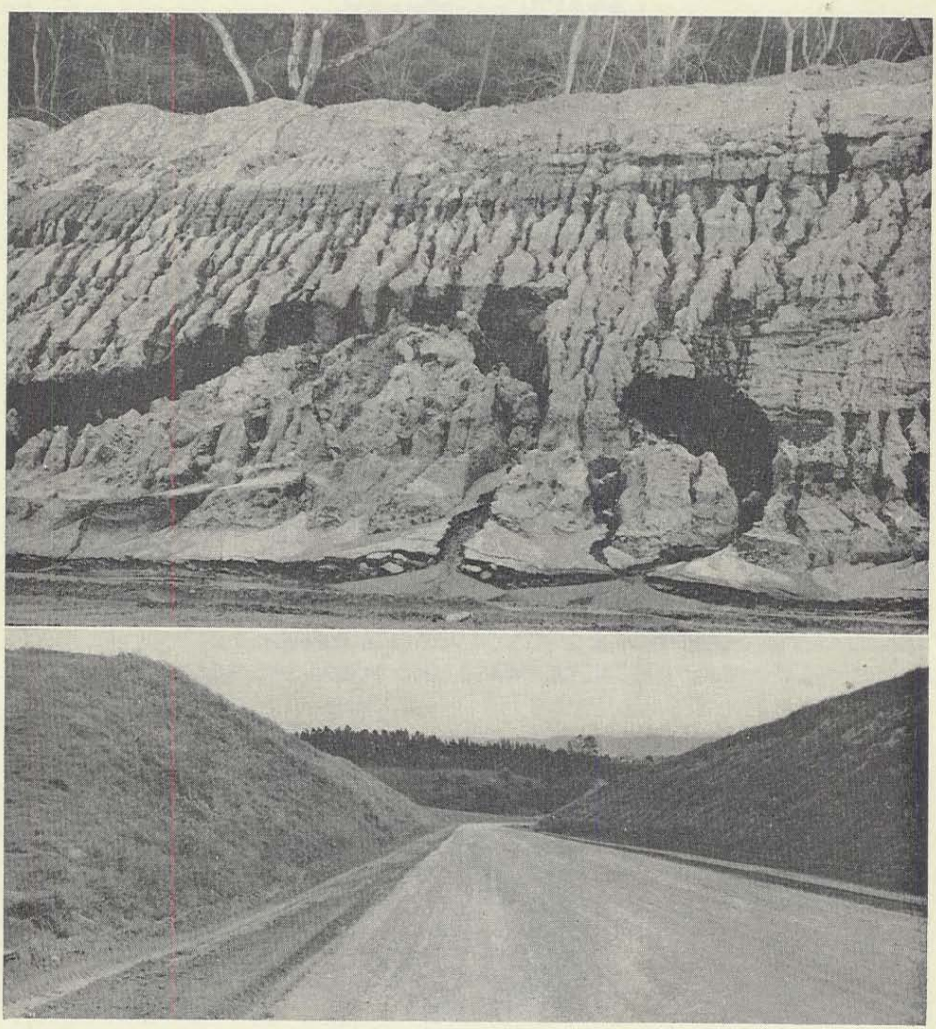
EROSION CONTROL ON CALIFORNIA STATE HIGHWAYS

REPRINT OF A SERIES OF ARTICLES PUBLISHED IN
"CALIFORNIA HIGHWAYS AND PUBLIC WORKS"

EARL WARREN
Governor

CHARLES H. PURCELL
Director of Public Works

GEORGE T. McCOY
State Highway Engineer



UPPER—Erosion caused by high-intensity storm during construction on untreated cut slope near Watsonville. Topsoil windrowed at top of slope. LOWER—Successfully stabilized cut slopes, same soil and locality as above, as they appear one year later. Treatment consisted of topsoil, straw and seed

FOREWORD

California, a wrinkled ribbon of land more than 800 miles long lying between the high Sierras and the Pacific Ocean, stretches from the humid forested zone characteristic of the Pacific Northwest to arid northern Mexico, and ranges in elevation from below sea level to more than 14,000 feet. Climatic variations are extreme, as might be expected, and erosion control problems vary correspondingly. Many different types of control have, therefore, been found to be necessary.

The purpose of this publication is to discuss the variable factors associated with erosion which affect California roadsides, review the development of erosion control methods by the State Division of Highways, and describe erosion control processes now being employed with reasonable success to stabilize slopes on California state highways.

It is felt that at least a few of the methods which have proved effective in California may be modified to suit conditions in other regions. Consequently, descriptions have been made as complete and are illustrated as fully as possible in order to permit duplication of these methods by nontechnical personnel.

The erosion problem on agricultural lands is another matter entirely. Since this phase of the subject is adequately treated in publications of the Soil Conservation Service we will consider here only erosion as it directly affects roadsides.

AUTHORSHIP AND ACKNOWLEDGMENTS

Grateful acknowledgment is hereby made by the author, H. Dana Bowers, Supervising Landscape Architect, Division of Highways, to the many persons who, by their suggestions and encouragement, have contributed to the preparation of this booklet.

Special acknowledgment is due Mr. Chas. C. Morris, Division Engineer of the Public Roads Administration, for suggesting that a publication describing our erosion control methods would be of interest to others faced with similar problems; and later for his review and suggested improvements in the manuscript. Also to Mr. Wilbur H. Simonson, Chief, Roadside Section, Public Roads Administration; Mr. C. J. Kraebel, Division of Forest Influences, U. S. Forest Service; Mr. J. S. Horton, San Dimas Experimental Forest, U. S. Forest Service; Professor Joseph Kittredge, Professor of Forestry, Forest Influences, University of California; and Mr. C. H. Gleason, Forester, U. S. Forest Service, for their valuable suggestions and constructive criticism; and to L. S. Manning, Associate Landscape Architect, California Division of Highways, for his compilation of this manuscript.

TABLE OF CONTENTS

	Page
FOREWORD	III
PART I—FACTORS AND PROBLEMS ASSOCIATED WITH EROSION	
California Climate and Rainfall	1
Erosive Soil Types	4
Erosion on Undisturbed Slopes	5
Development of the Erosion Control Problem	6
PART II—GENERAL EROSION CONTROL PROCEDURES	
Erosion Control on Cut Slopes	10
Erosion Control on Fill Slopes	14
Erosion Control on Highway Shoulders	18
Erosion Control in Drainage Channels	20
Wind Erosion	23
Seeding and Ground Cover Planting	26
Tree and Shrub Planting	30
Fire Hazards and Erosion Control	33
Maintenance of Erosion Control Work	36
PART III—DETAILED METHODS OF EROSION CONTROL	
Type A Stabilization for Steep Slopes	39
Type B Stabilization for Certain 1½:1 Slopes	40
Type C Stabilization for Slopes 1½:1 and Flatter	42
Brush Layer Method for Stabilization of Extremely Erodible Fill Slopes	44
Straw or Brush Wattle Method	48
Rock Method for Fill Slope Stabilization	48
Use of Straw Mulches in Slope Stabilization	50
Use of Sheepsfoot Roller in Slope Stabilization	51
Repair of Failures on Newly Stabilized Slopes	53
Repair of Old Eroded Slopes	55
Conclusions	59
APPENDIX	
Specifications—Erosion Control, General	63
Specifications—Erosion Control, Typical Special Provisions	65
Specifications—Erosion Control, Ground Cover Planting	67
Specifications—Typical Tree, Shrub and Ground Cover Planting	68

PART I

FACTORS AND PROBLEMS ASSOCIATED WITH EROSION

CALIFORNIA CLIMATE AND RAINFALL

CALIFORNIA climate has been the inspiration for so many clever remarks that its true nature is not widely understood. Perhaps a short discussion of the general climatic pattern and the extreme variations from the average which modify that pattern will be of value in explaining why California problems in erosion control are somewhat different from those encountered elsewhere.

Generally speaking, rain normally falls only during the late fall, winter and early spring months, with the greater part of the yearly total coming in the form of rains of high intensity during the months of December, January, and February. March and October may or may not be wet. Little or no rain falls from April to September.

Daytime temperatures during the dry summer range from moderate (average about 85 degrees) in the coastal areas and in the mountains at elevations above approximately 3,000 feet to high (average 95 degrees to 100 degrees) in the interior valleys. Humidity is low, except on the immediate coast, where fogs are general during July and August from Santa Barbara northward.

The yearly rainfall total varies strikingly from one section of the State to another. Highest rainfall figures are found in the vicinity of Crescent City in the northwest corner of the State, where the 20-year average is 72 inches per year, and yearly totals sometimes exceed 100 inches. Lowest figures are found in the southeast corner of the

Redwood trees and luxuriant undergrowth characteristic of the north coastal section of the State where yearly rainfall totals are high (Near Dyerville, Humboldt County)

Joshua trees (Yucca brevifolia) and sparse undergrowth characteristic of the southeast section of the State. Yearly rainfall totals here range from 2½ inches to 5 inches

State in the Imperial Valley (Brawley, 2.44 inches per year) and the southern end of the San Joaquin Valley (Bakersfield, 5.71 inches per year). In general, the northern part of the State receives an ample supply of rain, the quantity decreasing rapidly in the interior valleys as we move southward, and more slowly along the coast and in the Sierras (San Francisco, 23 inches; Sacramento, 19 inches; Tahoe, 31 inches).

This tendency is modified as the Tehachapi Range is crossed and the entire Southern California area receives relatively light rainfall (San Diego, 10 inches; Los Angeles, 15 inches) except in the higher mountains, where the yearly totals are much greater. Mount Wilson, for example, receives 31 inches of rain per year, while Pasadena, at its base, receives 18 inches.

Rainfall Intensity

It should be mentioned here that rainfall intensity in the mountains of Southern California is considerably higher than the yearly rainfall average might suggest. The influence of lower temperature and higher altitude of the mountains upon the warm moist air and clouds which drift inland from the Pacific Ocean results in the concentration of precipitation within a relatively small area. An intensity record for the North American continent of 1.02 inches during a one-minute period is held by Opid's Camp near Mount Wilson. Localized summer and fall thunderstorms also occur occasionally, and though they may contribute little to the annual rainfall total, serious erosion is often caused because of their high intensity.

The "unusual" nature of California weather is manifested in frequent deviations from the normal. Some years, the summer drought continues until December or even January. Occasionally, little or no rain falls after January or February, and at other times a period of fair rainfall in fall will be followed by one or two months of rainless weather, after which there may be late spring rains.

Vegetation Growth

Since soil moisture is depleted during the dry summer, growth of annual vegetation follows the rainfall pattern. The growing season starts with the first rain of the season, whether it comes in October or January, continues through the winter and spring, and all but the most drought-resistant plants die when soil moisture is no longer available. A light early rain, which starts the growth of annuals, followed by a dry period, sometimes results in the premature death of the first plants. A second crop then germinates after the next rain.

From an erosion control standpoint, these weather variations leave something to be desired. When the first rain of the season is moderate in intensity and deposits sufficient moisture to germinate seed and keep it growing, there is a good chance that an adequate vegetative cover will be established before the heavy rains come. But if the first rain of the season is late and heavy, the protection offered by the dead remnants of the previous season's growth is often inadequate, unless an ample root mat has been formed, and soil loss takes place.

On rural highways, establishment of a protective growth by artificially sprinkling the slopes has been attempted during dry years. This method, however, is not now considered practical for any but newly constructed slopes, and then only when conditions are such that subsurface moisture is present to augment the shallow penetration obtainable by sprinkling.

Highly erosive soil near Salinas. Note loss of soil above fence line. Sloughed material bladed off traveled way must be hauled away by truck

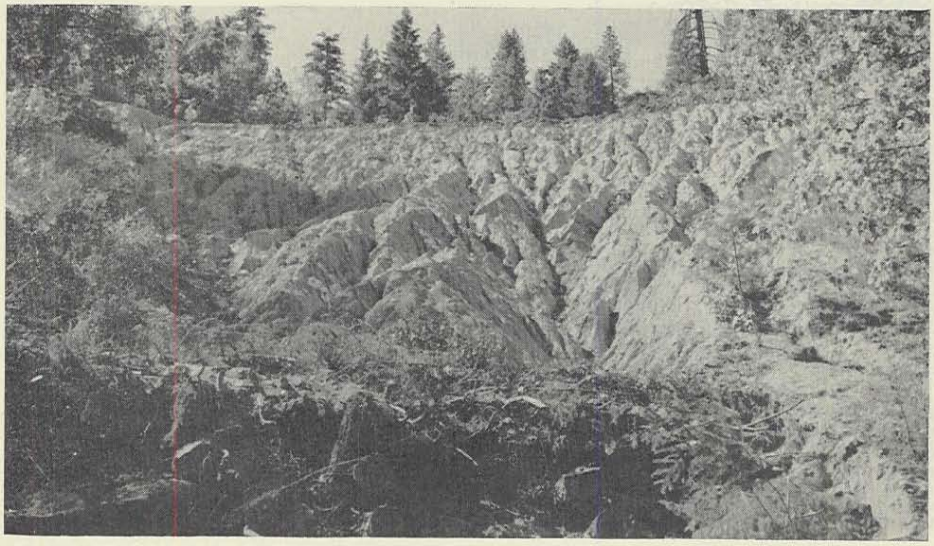
EROSIVE SOIL TYPES

In 1937, the United States Department of Agriculture recognized 259 distinct soil types as occurring in the agricultural sections of the State. As more comprehensive soil surveys are made, there is no doubt that many additional soil series will be classified, making the extreme complexity of the erosion control problem more evident.

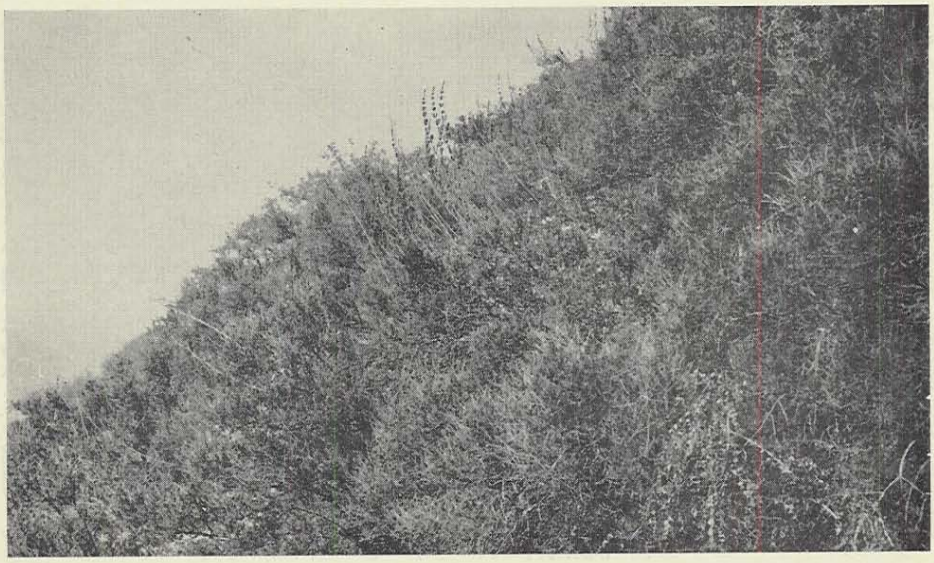
Most soils in the coastal portions of California are derived from material which is itself sedimentary in origin. Ancient ocean beds and river channels, raised high above the present sea level long ages ago, have been exposed to the elements and have eroded, forming new sedimentary deposits. These newer deposits erode still more readily, and after the erosion and deposition process has been repeated several times, the material becomes extremely susceptible to displacement by running water.

The readiness with which sedimentary material erodes depends upon the extent to which consolidation or compaction, and, later, disintegration have taken place. Recently deposited, poorly consolidated sediments, examples of which are found in the Salinas-Watsonville area, are extremely erosive. As a rule, other sedimentary materials, such as shale and sandstone, are less subject to erosion except when poorly consolidated or disintegrated, but are often troublesome from a control standpoint.

Material derived from igneous and metamorphic rocks, such as granites and gneisses, is also highly erosive. Such material is commonly referred to as "disintegrated granite." Since this material occurs in mountain areas where rainfall intensities are severe, erosion control measures required for control must be elaborate and thorough.



Roadway fill slope composed of disintegrated granite material after high-intensity rains. (Between Redding and Weaverville, Shasta County)



A naturally stabilized slope. No active erosion here

EROSION ON UNDISTURBED SLOPES

When considering the problem of soil loss on highway cut and fill slopes, the absence of accelerated erosion on undisturbed steep surfaces, invites speculation. On the natural slope a cover of vegetation which breaks the force of falling raindrops, a litter of twigs, grasses and leafmold or forest duff, which retard the runoff of surplus water, and the presence of a coating of moderately compacted topsoil, appear to be the prime factors which differentiate disturbed and undisturbed slopes.

The angle of slope and the composition of subsoil may be identical, yet the disturbed slope loses large quantities of soil with every rain while the natural and undisturbed slope remains unaffected. The obvious thing to do, then, is to endeavor to duplicate on the artificial slope the conditions which prevent damage on the natural slope. That, however, is not always a simple matter.

Natural Slope

The natural slope which we see protected so effectively has attained its condition of equilibrium only after a period of many years' exposure to the elements. If the slope was first formed by rapid cutting action of a stream, or, perhaps, by sliding earth or even volcanic action, it was subject to the same violent erosive forces as our highway slope is today, and gullied just as badly. Very slowly, however, a few windblown seeds found lodging places on the gullied slope and grew into stunted plants which helped catch more seeds. Gradually, during seasons of moderate rainfall and ideal conditions, vegetation spread, and as it increased in density, more and more leaves and twigs fell to the earth to act as tiny

Nature covers eroded slopes with vegetation, but it is not a quick process. (Junction of the Trinity and Klamath Rivers, Humboldt County)

dams to prevent soil loss and to do their part toward development of humus and topsoil. Eventually, the slope became completely stabilized; but note that it took many years and that many tons of soil eroded from the slope before soil loss became negligible.

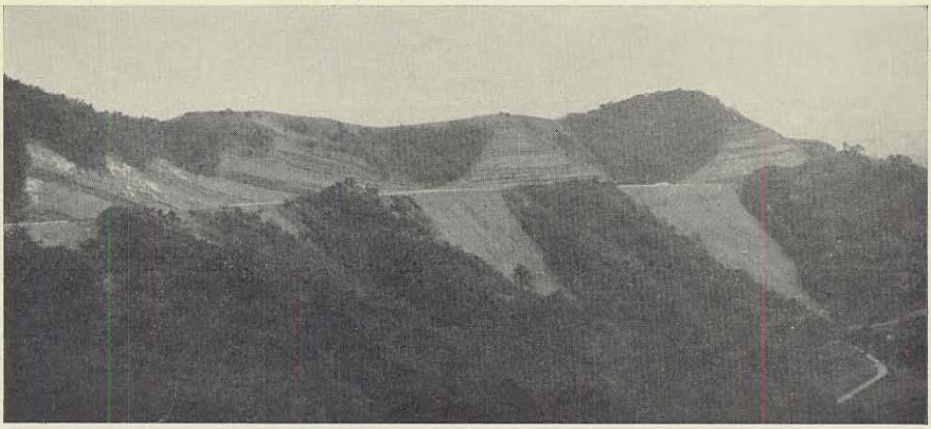
Nature Must Be Helped

Unfortunately, we cannot wait many years for unassisted nature to heal the wounds we have made in the earth Soil which has eroded from new banks affects our highways adversely, and even though it may be true that eventually the slopes will stabilize themselves, the maintenance cost in the meantime, which can be charged directly or indirectly to soil loss, is often excessive. Nature must be given a helping hand if we are to expect rapid stabilization.

DEVELOPMENT OF THE EROSION CONTROL PROBLEM

As long as man was content to jog along on his horse or in his wagon taking it as a matter of course that he must spend many hours in traveling a few miles, roads were built over the easiest terrain. When the early roadbuilders encountered a hill, they built their road straight over the hill or went around it. Excavation was kept to a minimum since the speed of vehicles of that day was slow, and cuts and fills constructed by hand or horse labor were costly. Erosion took place, but people considered ruts, washouts, and slides as unavoidable evils, and if a road became impassable, they either went around the bad place or stayed at home. If the road was badly damaged, it was often cheaper to build a new road entirely than to repair the old one. There was plenty of land, and the investment in the old road was not great. Nobody thought much about erosion, except during the rainy season, and even then the rain was blamed for the difficulties rather than the roadbuilders.

Came the day, however, when people began to demand "All Year Roads."



Extensive cut and fill area exposed to erosive forces by construction of this high-standard mountain road. Compare with old road at lower right. (Near San Marcos Pass above Santa Barbara)

Satisfying the demand meant that a considerably greater investment had to be made in the existing road. Culverts, drainage ditches, improved subgrade, bridges and eventually hard-surfaced pavement, added to the cost. The demand for improved alignment to keep pace with modern automotive transportation and speed resulted in the construction of deeper cuts and higher fills. It was no longer cheaper to build a new road than to repair the existing one. So erosion became a problem.

The problem was treated in the obvious way. If soil washed onto the pavement, it was scraped off, or hauled and dumped over the nearest fill slopes. If gullies developed in drainage ditches

Adjacent property affected by debris from eroded highway drainage ditch. (On Coast Route, south of Half Moon Bay, San Mateo County)

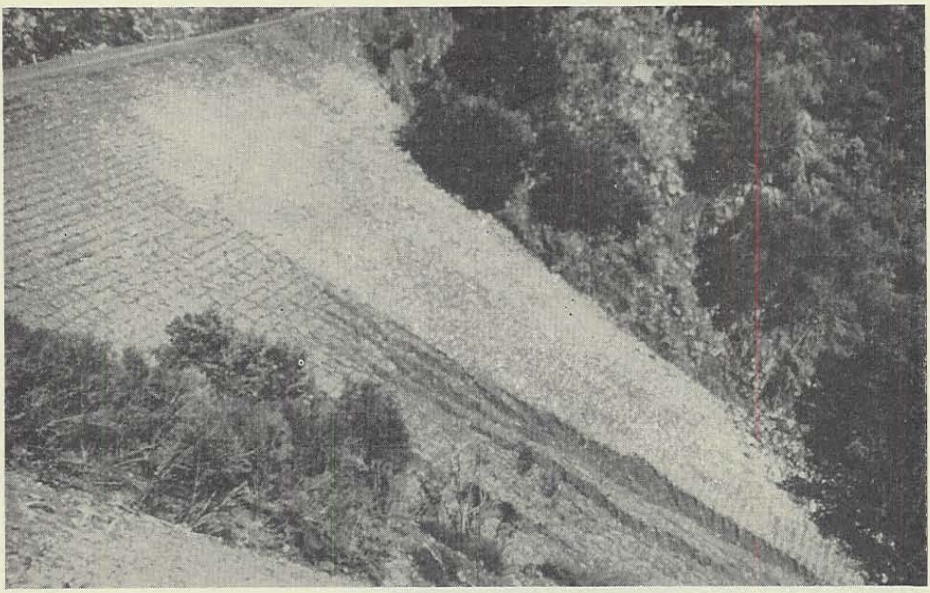
An early experiment in 1½:1 fill slope treatment. Iron pipe stakes and fencing fail to prevent slip out. Inadequate downdrains and resultant overtopping of the berm by surface runoff contributed to failure. (Crest Drive, San Bernardino County)

or fill slopes to the point where the pavement was threatened, they were filled up with loosely dumped soil. It was a race with Nature, an attempt to repair damage as fast as it occurred. Many of the gullies were washed out anew each year, growing larger each time. Areas from which soil washed onto the pavement deposited more and more soil with each storm. True, some of the troublesome areas were "cured" in time, but for the most part it was a losing race.

Roadside Appearance Suffers

In addition to the danger to traffic and the roadway, due to the effects of erosion, the appearance of the roadside suffered. Adjacent property was affected by concentrated or diverted water and the deposition of eroded debris, and many damage claims resulted. The cost to the public in loss of life and property due to accidents in which erosion damage was a factor, is incalculable.

Needless to say, as the alignment of highways improved, slopes and fills became higher, with a resultant increase in maintenance costs due to erosion damage. It was fully realized that some method must be developed to prevent this costly damage, prevention being proverbially better and cheaper than cure, but information on proven procedures was lacking and funds for experimental work were difficult to obtain. It was not until the depression period (in the '30's) that it was possible to get manpower and money for large-scale experimental projects. By this time, various agencies were developing control methods which looked good but which, for the most part, had not been tested under sufficiently varied conditions. A number of methods were tried and, of these, some showed considerable promise.



An early experiment in wattle spacing. Wattles widely spaced on left half of slope, closely spaced on right half. (Angeles Crest Highway, Los Angeles County)

Methods developed by the Forest Service, and described in Mr. Charles J. Kraebel's circular, "Erosion Control on Mountain Roads," and methods suggested by Soil Conservation Service publications and the Public Roads Administration were tested and modified by the California Division of Highways with varying results. Further experimental work has been done since that time, and the methods described herein represent the most successful of the many procedures which have been tested. It is not to be expected that these methods will be the final answer to the slope stabilization problem. Since climate, rainfall and soil character vary so widely throughout California, no one method can possibly fit all conditions without modification.

Experimental work is continuing, however, and it is hoped that methods will soon be developed which can be relied upon to give adequate control under extremely adverse conditions.

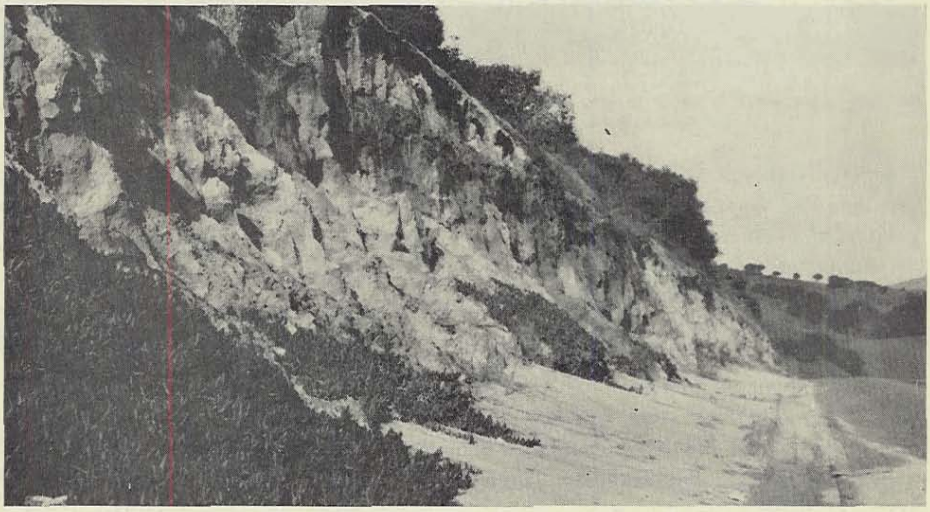
PART II

GENERAL EROSION CONTROL PROCEDURES

EROSION CONTROL ON CUT SLOPES

When soil is eroded from a highway cut slope, it is generally deposited in such a position that it blocks drainage ditches, causes diversion of water onto the pavement, or is actually deposited on the pavement with consequent hazard to traffic. All these situations require immediate attention by maintenance forces, and every maintenance man knows what it is to be routed out of bed on a stormy night to clear mud off the roadway. Emergency maintenance is expensive, and the cost of cleaning sloughed material from drainage ditches in the spring and summer is no small item. A gullied cut slope is unattractive from the standpoint of appearance, and is undesirable for that reason even though no direct expenditure of money is involved.

It was realized, of course, that an attempt must be made to stop, or at least reduce, the loss of soil from the slopes, since most of the soil which was washed from the slope had to be disposed of. Many methods of control were tried. Cut slopes were made steeper, the idea being that on a very steep slope, a smaller area of slope face would be exposed to the elements, and less water would accumulate on the slope itself. That idea worked pretty well when the rain came straight down, but when the rain was driven by the wind directly against the slope face, the increased steepness of the slope



Active erosion on steep cut slopes. Vegetation cannot become established while soil particles are being constantly washed away. Note sloughed material which must be removed. (Near Salinas, Monterey County)

caused the water to run off with greater velocity, causing more damage. Native vegetation found it impossible to establish itself on the steep slope; consequently, soil loss was continuous.

Runoff Water Controlled

Intercepting ditches were constructed at the top of each cut slope to prevent runoff water from above, from pouring over the cut face. This restricted the amount of runoff water which could cause erosion in the critical area to that which actually fell on the cut face, and was of decided benefit in reducing soil loss. This practice is now standard. These ditches lose their value, however, if they are not kept clean to allow free flow of water.

Low cuts are not subject to serious or rapid soil loss. Runoff water which accumulates on a low slope face does not attain sufficient volume or velocity by the time it reaches the lower portion of the slope to move much soil, though the process of soil loss, while slow, is sure. It is logical that if a high cut slope were broken up by means of water-catching terraces so that, in effect, it was made up of a series of low banks, the same low soil loss characteristics would apply to the entire slope. Terraces then must be constructed so that they will intercept runoff water and sloughed material from the slope above and lead the water to one side where it must be carried to the bottom of the cut in lined ditches or culvert pipe.

This method works very well, provided the terraces are kept clean of slough so that no interference with the drainage system takes place; but the cost of extra excavation to form the terraces, plus the cost of lined ditch or pipe to dispose of runoff water safely, make it too expensive for any but exceptional cases. The appearance of a terraced slope is unpleasing because of the straight terrace lines which appear on the slope face. Mainly, however, it is a mechanical approach to a problem that can only be permanently solved by natural means.

Sandy cut slope south of Santa Maria, Santa Barbara County, which was stabilized by spraying with asphalt. The brittle coating has cracked, and failures are developing

Waterproofing a slope by coating the soil with an impervious substance is another mechanical and generally ineffective method. Unattractive appearance and cost of treatment, plus high maintenance cost, if a brittle substance is used, make this method impractical except in extreme cases.

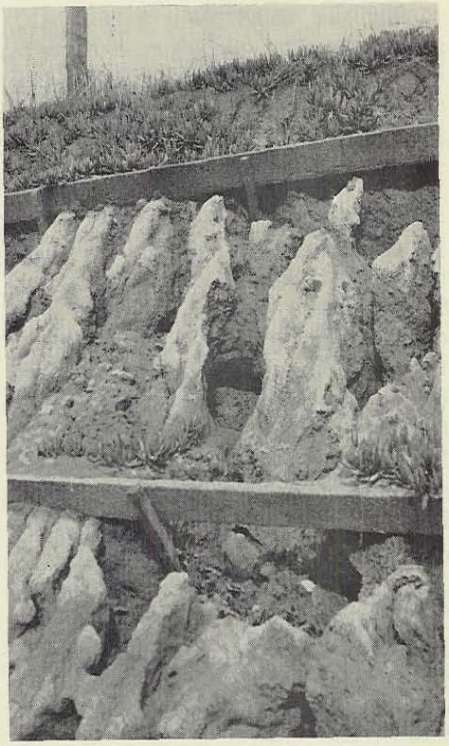
Terrace Slopes Eroded

The accompanying illustration shows what happens when small undrained terraces are constructed on a 1:1 cut slope in an attempt to create favorable conditions for ground cover plant growth (in this case, Mesembryanthemum). A ditch was dug in the slope, faced with a length of 1-inch x 4-inch lumber held in place by stakes, and the resulting space backfilled with topsoil, and planted. Runoff water overtopping the board facings dropped to the slope below, eroding the steep slope between terraces. Board facings were undermined, and further loss of saturated topsoil took place. As the illustration clearly shows, this method proved to be both expensive and unsuccessful.

The foregoing methods are all mechanical ways of combating natural forces. Observation of naturally formed slopes showed that native vegetation growing on the slope did a pretty good job of erosion control, and, furthermore, the appearance of such a slope was not unattractive because it *was* natural.

Thick Vegetative Cover

Attempts were made to establish vegetation on new 1:1 cut slopes. Grass and grain seed, cuttings of ground cover plants, and seed of native plants were planted on the steep slopes. For the most part, results were disappointing. Vegetation grew well at the top of the cuts where some topsoil had been left after slope-rounding operations were completed, and if the slope face was rough enough to form pockets which could hold topsoil, little tufts of vegetation grew in the pockets. The bare, smooth, exposed subsoil, however, could not maintain plant growth which was vigorous or dense enough to protect the entire slope from erosion, and the soil loss which took place during the establishment period was nearly as great as on untreated banks.



Board-faced, undrained terraces on a 1:1 cut slope are subject to undermining (Santa Barbara)

Favorable results obtained from some of these tests indicated clearly that a thick vegetative cover was effective in preventing loss of soil from the slopes. In order to establish this desirable thick vegetative cover, it is necessary to cover the sterile slope with a blanket of topsoil in which the plants can grow.

The angle of repose of loose soil is approximately 1½:1. It will sometimes stand on a steeper slope, but when saturated will slump and come to rest in an ungraceful heap at the bottom of the slope. Since it was obviously impossible to blanket a 1:1 cut slope with loose topsoil with any assurance that it would remain on the slope, even when dry, it became necessary to flatten the cut slopes to a minimum of 1½:1 in order to retain topsoil.

Slippage Overcome

A blanket of loose topsoil six inches or more in thickness was spread evenly on the smooth cut slopes; but if the first rain of the season amounted to several inches, this loose soil, becoming saturated, slid to the bottom of the slope, leaving the smooth subsoil exposed. It was found necessary to roughen the subsoil slope face and reduce the thickness and weight of the topsoil blanket in order to overcome the tendency toward slippage. A topsoil cover less than three inches in thickness was found to give as satisfactory results as a thicker blanket, since density of growth, not size of the individual plant, is the desirable condition.

The combination of 1½:1, or preferably flatter slope, well roughened cut face, and relatively thin blanket of topsoil, seeded with grain or grass seed, works very well in all but the most erosive types of California soils. Barring the years when an "unusual" amount of rain falls at the very beginning of the rainy season, soil loss is not great before vegetation becomes established, and is negligible thereafter.

Highly Erosive Soil Types

The highly erosive soil types, however, offer additional problems. Some soils seem to melt like sugar under the influence of rainfall, and when treated as above, the soil loss during the first year is so great as to make it almost impossible to establish vegetation on the slope.

To solve this problem, straw was spread over the topsoil after seeding in an attempt to duplicate the humus existing on natural slopes in the vicin-

A thick (6±") uncompacted topsoil blanket slips from 1½:1 slope when saturated (Near Castroville, Monterey County)

ity. The straw retarded surface erosion by decreasing the velocity of runoff water. It also encouraged the germination of seed but increased the tendency toward saturation and consequent slippage of the topsoil. Stakes were driven through the topsoil layer and into the subsoil in an attempt to anchor the soil and straw in place, but this proved unsatisfactory.

A sheepsfoot roller was used on the mulched and topsoiled slope in order to compact the topsoil to the point where its water-holding capacity would be reduced, and the tendency of the soil to liquefy would not be so pronounced. The roller was rigged and operated as described later and performed the double function of compacting the slope surface and incorporating the straw with the soil in one operation.

This method gives very satisfactory control of even the most erosive soils during years when rainfall is normal, but partial failure results due to slippage when rainfall exceeds three inches to four inches in a single storm during the first year after treatment.

A straw-covered, topsoiled, 1½:1 cut slope after compaction with a sheepsfoot roller. (Near Salinas)

EROSION CONTROL ON FILL SLOPES

When soil is eroded from fill slopes, the immediate effect on the traveled way is not often serious. The usability of the highway is generally not immediately affected, and unless a slipout takes place or a gully erodes to the point where it starts eating into the roadway, these minor soil losses have generally been disregarded until the small gullies have attained major proportions. By that time, extensive repairs are necessary in order to save the highway.

Vegetation, of course, offers the most economical and effective means of control.

Results of sowing seed on raw fill slopes before the soil had been consolidated by rain, were very encouraging. In all but highly erosive or very infertile soils, one seeding usually produced a sufficiently dense cover to give

Soil loss after a high-intensity storm on an untreated fill slope in the vicinity of Watsonville. This slope later received seed and straw treatment and is now perfectly stabilized

adequate control after the first year. Old fill slopes which had been consolidated and gullied by rainfall before being seeded showed poor results, much like those obtained on smooth cut slopes, unless roughened by cultivation before seed was sown. Under some conditions it was found that an application of straw mulch or some type of humus was necessary in order to prevent the gullies from redeveloping before the seed germinated. An effective cover was established on very infertile soils after an application of fertilizer or a thin blanket of topsoil was spread on the slope. The results of sowing seed on new fill slopes before they are consolidated by rain are usually so successful and the cost is so relatively small that this practice should be followed on all newly constructed roads.

While seeding alone (at times supplemented by a straw mulch) gives adequate control in localities where the soil is neither highly erosive nor subject to heavy concentrations of rainfall, more elaborate treatment is necessary where conditions are extreme. Loss of soil due to gullying and sheet erosion may be retarded during the critical first season before vegetation has become established, by applying straw as a mulch. The straw protects the soil surface from the impact of the raindrops, and slows the runoff water down to the point where its velocity is so low that its soil-carrying capacity is practically nil.

Theoretically, a small quantity of water runs from straw to straw and reaches the bottom of the slope without touching the soil at all. If it were practicable to "thatch" slopes with a thick covering of straw, each straw running in the same direction, the problem of surface protection should be solved until the straw rotted, or became displaced. However, it is desirable that enough moisture be absorbed by the soil to support plant growth, which will give permanent protection, so waterproofing the slope does not completely solve the problem.

The protection given the surface by a straw application is effective only as

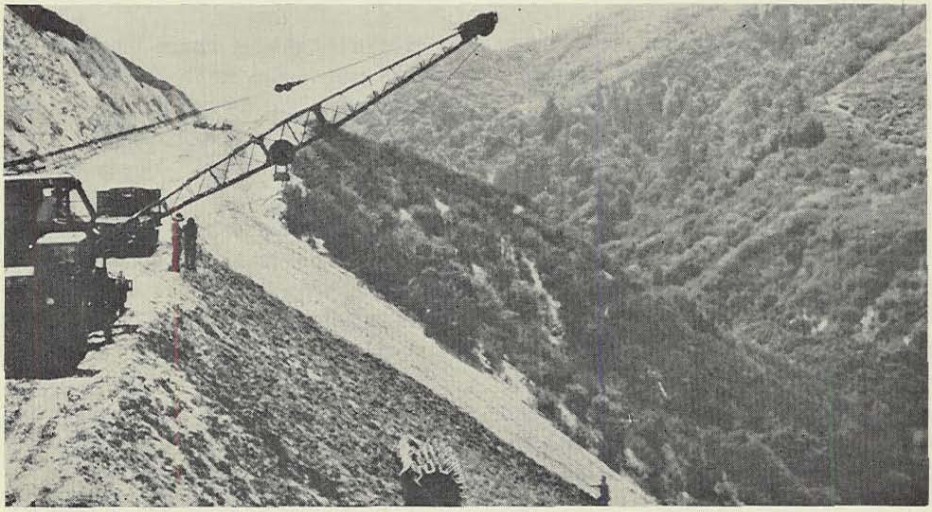
long as the covering remains unbroken. If a culvert or berm fails or is overtopped, thereby concentrating a quantity of water in a single area, the straw covering is washed away in a short time and the gully deepens rapidly. If workmen, children, or animals have made trails or have otherwise disturbed the cover, gullies may form.

In order to give the protection of which it is capable, a straw covering must be inspected at frequent intervals, especially during the first season, and disturbed areas seeded and repaired with additional straw before extensive damage is done.

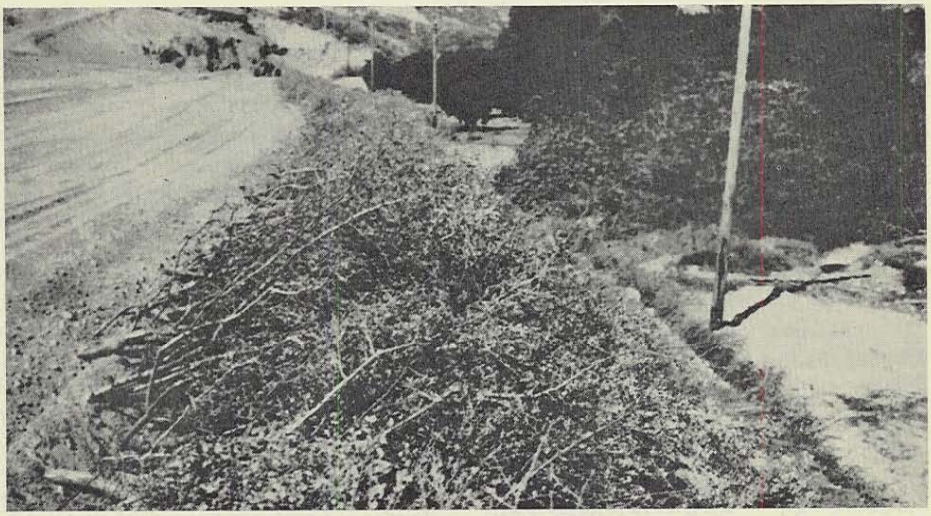
Unfortunately, one of the advantages of a straw covering from a surface-protection standpoint, turns out to be a distinct disadvantage in another way. Straw reduces the velocity of the runoff water, and as a result percolation of water into the loose outer layer of the fill material is increased. Most of our California soils will slump, slide or run like molasses when saturated, so some means had to be provided to decrease the amount of water which could be absorbed by the soil and also to anchor the outer layer which is subject to slippage.

A sheepsfoot roller was run over the completed slope (as described later) in order to compact the soil. Since the straw is spread on the slope in advance of rolling, it is incorporated with the surface soil as the compacting is done, thus performing two operations simultaneously. A sheepsfoot roller leaves a few inches of loose uncompacted soil on the surface, but this loose soil is mixed with straw and forms a good seedbed for the grain seed which is sowed as part of the complete treatment.

A relative compaction of 89.4 percent was obtained below the top four inches on a disintegrated granite fill slope which had recently been given six round trips of a standard two-section sheepsfoot roller. This degree of compaction reduces the water-holding capacity of the soil by reducing the number of voids, and the tendency of the soil to liquefy is not so pronounced.



Rolling straw-covered 1½:1 slope with a sheepsfoot roller (City Creek Road, San Bernardino County)



Brush layer in place ready for a covering of soil, which is then compacted (City Creek Road, San Bernardino County)

On deep fill slopes composed of highly erosive material, a mechanical anchoring effect may be obtained by the use of wire-reinforced brush mats, straw or wire-mesh mats, or brush layers installed on the contour during fill construction. The various types used are described later. All types are placed flat during construction, on a contour level, with the outer edge of the mat or layer flush with the surface of the fill, and the inner edge buried about five feet in the solidly compacted fill material. The relatively loose outer layer of soil is thus stabilized to a large extent, even when saturated.

Mats Act as Screens

The mats and layers are also designed to act as screens or filters in the event the surface straw protection does not completely prevent movement of soil particles. If gullies start to form due to failure of the straw covering, the mats or layers are exposed, and by filtering and decreasing the velocity of the water, tend to keep the damage to a minimum. Thus the mats and layers act as a second line of defense and are not utilized, except as mechanical anchors, unless the surface protection fails.

The outer edge of the mat is left flush with the surface of the fill slope to allow for use of a sheepsfoot roller in compacting the loose surface material and imbedding straw in the soil without disturbing the mat.

A further reason that brush should not protrude beyond the slope face is based on observation of brush-layer-treated slopes on which the brush had been allowed to protrude 12 inches or more from the slope. Where any soil movement whatever took place, the filtering action of the brush caused terraces to build out on the protruding brush layer to the point where run-off water, overtopping the terrace, dropped straight down, striking the slope below with considerable force. Holes were gouged out in the slope below the layer, and the displaced fill material which was carried down to the next brush layer accelerated the formation of a terrace at that point.

This same effect takes place, of course, when the brush layers which have been constructed flush with the edge of the fill, are exposed by failure of the surface protection. The terraces are not built up so rapidly, however, and are confined to the actual gully area.

The conclusion has been reached that since no method of erosion control yet observed is completely successful during the first year under extreme conditions, a treatment which is relatively inexpensive to install and which can be used to repair failures as soon as they are observed seems more practical on a long-term basis than more elaborate and costly methods.

Findings of Conference

The following paragraph is taken from a paper entitled, "Erosion Control Specifications for Southern California," which summarizes conclusions reached at a conference between representatives of the U. S. Forest Service and the California Division of Highways in April, 1946:

"Material excavated from cuts and placed in fills in mountainous areas is not a soil but a broken and shattered rock, which is incapable of supporting vegetation until soil forming processes have had an opportunity to operate. Where this material comes from a rock which is geologically fresh, it is usually in rather large fragments and does not contain sufficient fines to retain moisture and support growth. Plant food elements may be sufficient in the parent rock, but they are not available until degeneration takes place. Natural revegetation can not succeed until such time as this material becomes a partly developed soil. This requires weathering, the introduction of organic matter with the consequent formation of humus, and the development of soil bacteria for nitrogen fixation and assistance to plant growth. Where the fill does not naturally contain at least 60 percent of material passing the No. 12 sieve and 18 percent passing the No. 200 sieve, the period required for sufficient weathering to take place to make a soil capable of supporting vegetation is too long for economic consideration. To overcome this condition, sufficient fine material must be added to meet this specification in the outer two feet of the fill material."

EROSION CONTROL ON HIGHWAY SHOULDERS

Damage due to erosion on highway shoulders is generally confined to the development of numerous rills or small gullies in highly erosive granular material caused by runoff water from the pavement. This development is most likely to occur during the first year after construction, before the shoulder has become stabilized by traffic compaction and a growth of vegetation, but seldom thereafter.

In view of the temporary nature of this problem and the simplicity, effectiveness and low cost of the curative treatment herein described, it would seem that construction of an expensive bordering plant-mix berm for the sole purpose of stopping off-pavement erosion may not always be justifiable.

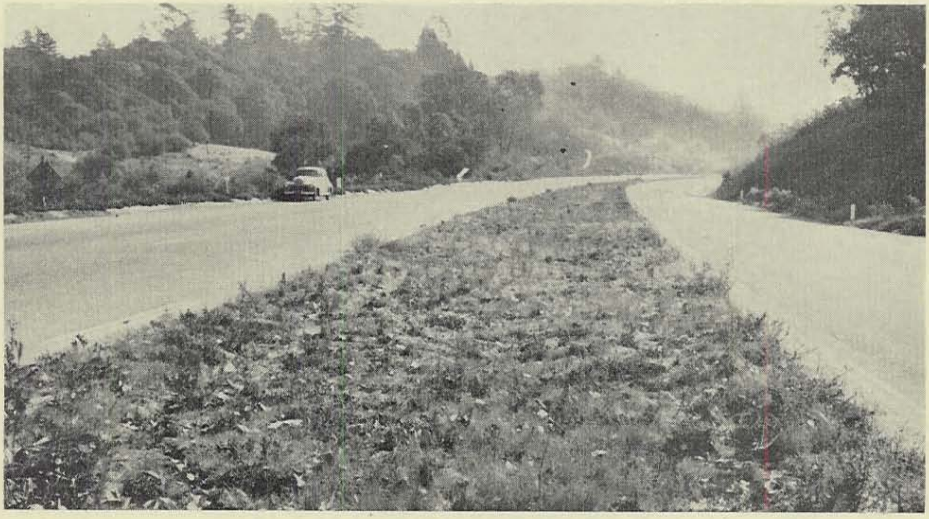
Since erosion damage to shoulders, even when normally erosive imported material is used, is almost entirely dependent upon the intensity of the rainfall during the first year, erosion protection is not given shoulders as a matter of course. If rills develop, a thin coating of straw spread at the rate of approximately three tons per acre, is scattered over the affected area and a sheepsfoot roller is run over the straw, thus punching it into the soil. Under extreme conditions, the area is seeded, though normally an adequate grass cover is obtained from seed contained

Small gullies caused by runoff water from the pavement (Box Springs Grade, Riverside County)

in the straw and from native vegetation which will establish itself after the first rainy season.

Uncurbed center dividing strips are subject to the same type of damage, and curative measures are much the same as those described above. Additional protection may be found necessary in the low center which becomes a drainage ditch, but well vegetated ditches of this type running on grades as steep as 5 percent have been disposing of runoff water without loss of soil. Where climatic conditions are favorable an evergreen ground cover planting will solve the protection problem.

Establishment of evergreen turf on highway shoulders, as is done in regions which receive summer rainfall,



Vegetative protection in a dividing strip on an approximate 5 percent grade. No damage is evident. Soil is the same as in fill slope, Page 15. (Between Watsonville and Santa Cruz, Santa Cruz County)

has not been found practical in California. No perennial grass has yet been found which will survive the long dry summer season without being given artificial watering. On metropolitan freeways where elaborate landscape treatment justifies the installation of a sprinkling system, a strip of grass can be established on the shoulder to act as an emergency parking area and to control dust and erosion, but for the most part, in rural areas we must depend upon annual grasses and weeds to hold the soil.

EROSION CONTROL IN DRAINAGE CHANNELS

EVERY HIGHWAY user is familiar with the sight of eroded drainage or intercepting ditches, which are both ugly in appearance and potentially dangerous to traffic. So far, little consideration has been given to the possibility of preventing this damage, yet methods have been developed which offer an effective and inexpensive means of control if applied at the right time, which is during construction.

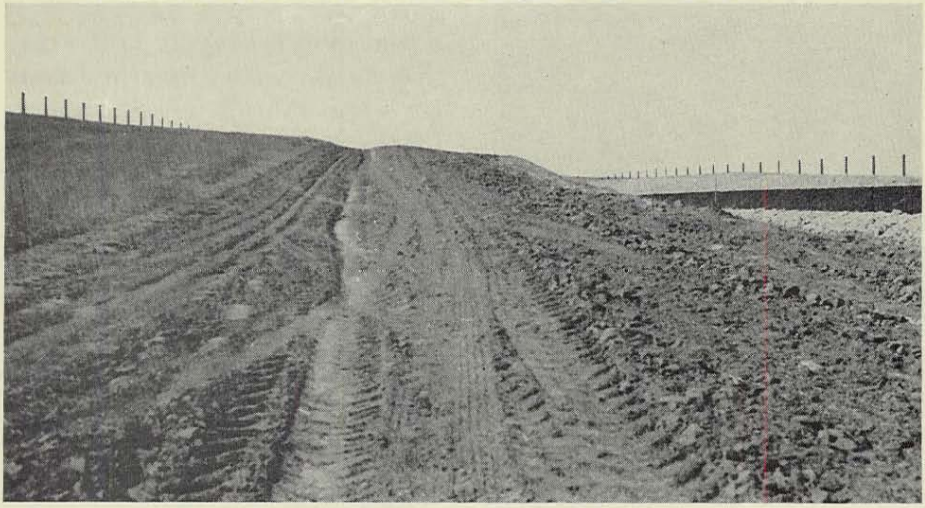
An unvegetated ditch, formed in soil which is even moderately erosive, cannot carry an appreciable amount of water on a grade steeper than 2 percent without losing soil. As the grade of the ditch becomes steeper, the velocity of the water increases and, of course, the rate of soil loss increases with the velocity. That is elementary. Yet new ditches are still being built on steep grades by equipment which forms a V-shaped ditch with the point of the V extending into the infertile subsoil —an open invitation to erosion.

Quite often, it is true, the ditch is not called upon to carry water until vegetation has established itself naturally where it can find a foothold, and erosion is lessened or eliminated by the retarding effect which the vegetation has upon swiftly moving water. However, when the intensity of rainfall during the first year after construction is so great that the ditch must carry runoff water, the bottom of the ditch will

An unattractive intercepting ditch. Culverts may be clogged with eroded material when this type of soil loss occurs (Near Shingle Springs, El Dorado County)

usually scour clean and the hard subsoil which is then exposed offers no foothold in which windblown native seeds can lodge. Lacking protection, the ditch gets deeper with every storm, and as the depth increases, the likelihood of natural establishment of a protective growth of weeds and grasses becomes less and less.

steep grades with equipment now in general use. Too much hand work is necessary. An alternate method of intercepting runoff water may be employed, if space and character of the soil permit. A thin layer of topsoil is scraped from the slope immediately above the top of the slope face, and formed into a low rounded berm



A broad, flattened, intercepting ditch. Vegetation may easily be established here, and a large volume of water carried without damage (Near Castroville, Monterey County)

A ditch formed in a broad U-shape instead of the sharp V-shape, need not extend as deeply into the infertile subsoil in order to carry an equal amount of runoff water. Concentration of water in a single channel is reduced. If the bottom of the ditch is cultivated, covered with a thin layer of topsoil, if necessary, and seeded with a quick-growing annual grain immediately after construction, protection may be obtained during the critical first year, and the windblown native seeds caught by the grain stalks will establish a permanent cover quite rapidly.

While the broad U-shape is most desirable, it is admittedly impractical to construct a ditch of this shape on

which merges into the rounded brow of the cut. This may be done with a motor grader. The disturbed area is then cultivated and both it and the berm are heavily seeded. Concentration of runoff water in the area immediately behind and against the berm takes place, of course, but conditions for vegetative growth are so much more favorable in the topsoil of which the berm is composed that growth is usually rapid and dense.

Well vegetated ditches of this type are capable of handling intermittent runoff water effectively, and under normal conditions no erosion takes place even on steep grades.

An unvegetated drainage ditch may erode to the point where the roadway is threatened (Box Springs Grade, Riverside County)

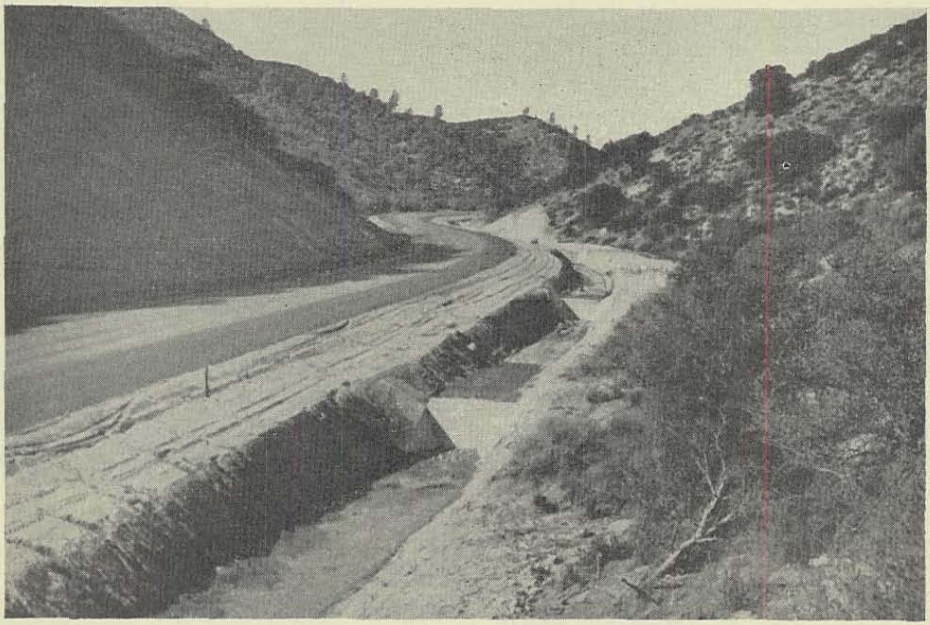
A straw mulch may be found necessary, under certain conditions, to afford immediate protection from erosion before the nurse crop appears or even to stop developing gullies in a partly established planting, but this additional treatment is seldom required.

Under certain conditions the construction of contour ditches at the ends of cut slopes makes it possible to dispose of runoff water without inviting soil loss. If the right of way is wide enough, and the shape of the end slope permits, water can be directed away from the roadway to a dispersal area or, if the adjoining property owner does not object, to the naturally sodded field beyond the fence line where it can do no damage.

Erosion damage in roadside ditches which run on a moderate grade may be stopped relatively easily. Cut brush, packed into the ditches, supplemented with straw, if the brush is coarse in texture, will filter soil particles from the water and reduce the velocity to the point where no further cutting action takes place. With active erosion eliminated, vegetation has an opportunity to become established and, if given a little encouragement, will form a permanent protection. Where possible, diversion of a portion of the runoff water through a supplementary channel until vegetation has become established is advisable in order to hasten the stabilization process.

Check dams are sometimes necessary when the soil is very erosive and the grade is long and quite steep. Those used along our highways are usually made of concrete, and are so placed that the grade from the foot of one to the crest of the next does not exceed 2 percent.

Cut brush placed in eroded drainage ditch arrests active erosion (Near Tunitas, San Mateo County)



Concrete check dams retard velocity of runoff water on a steep grade (Between Bradley and Jolon, Monterey County)

WIND EROSION

When roadway excavations are made through incompletely stabilized sand dunes or the roadway lies in the path of active dunes, wind erosion with the resulting drifting sand becomes a serious problem.

Mechanical methods of control; for example, spraying the sand banks with liquid asphalt, have the advantage of stopping soil movement immediately, but maintenance cost is usually high and increases yearly until finally the original treatment must be repeated. This type of control cannot be considered permanent.

In arid or infertile areas where plant growth is naturally sparse and rock or gravel is plentiful, some form of the mechanical method of control illustrated (p. 24) may be utilized. The cost of hand placing rock in this manner is high, but this expense may be justified under extreme conditions. A blanket of coarse gravel is also reasonably effective when conditions are not favorable for vegetative growth.

Vegetative stabilization of areas subject to wind erosion is both practical and inexpensive. A topsoil blanket, supplemented by seeding, is often sufficient to stop soil loss. If no topsoil is available, seeding, followed by application of a straw mulch worked into the soil with a sheepsfoot roller is usually effective. In extreme cases where the soil is very loose and the wind velocity high, seeding followed by application of a layer of cut brush will give control.

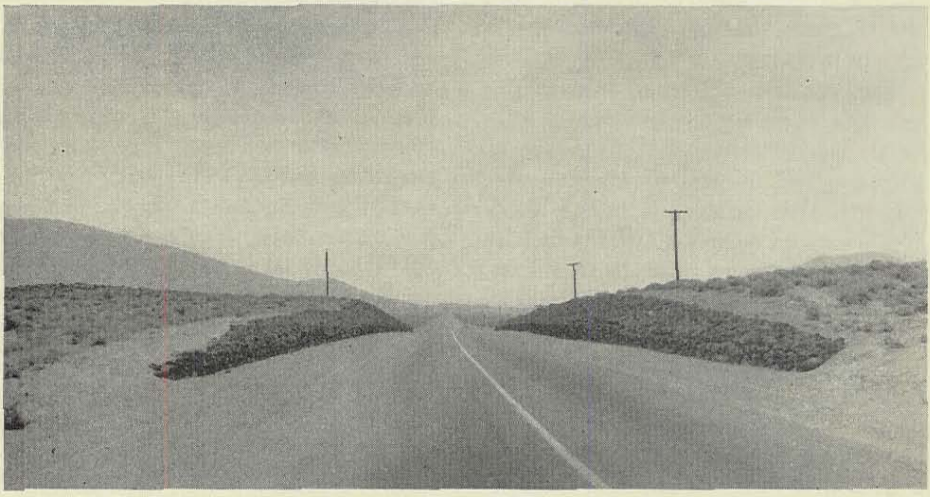
With any of these methods, the function of the humus, mulch or brush is largely to suppress movement of the soil until plants have become established, after which the vegetation alone gives adequate protection.

Wind erosion affects both the sandy cut clope and the traveled way. (Near Carmel, Monterey County)

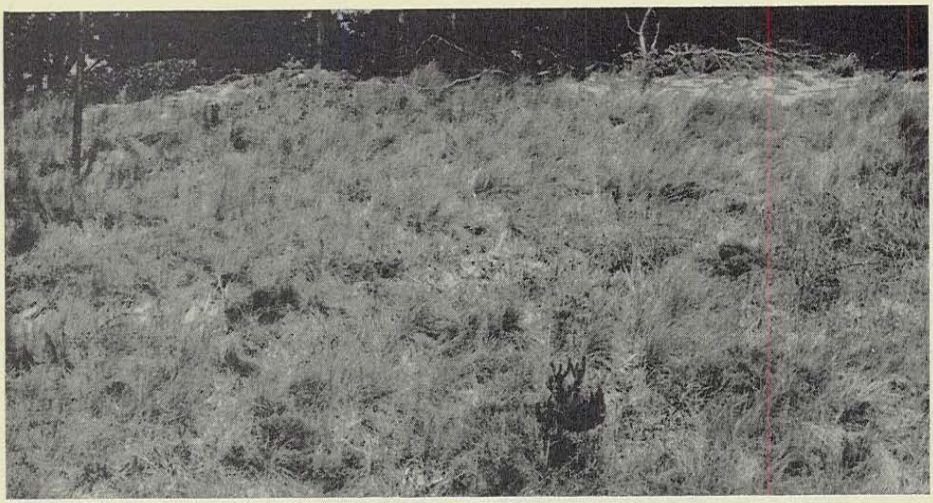
Moving sand dunes which threaten to overwhelm a highway may be stopped in their tracks by making use of the beach grass which John McLaren found so effective when he reclaimed dune country and transformed wasteland into Golden Gate Park in San Francisco.

European beach grass (*Ammophila arenaria*), a perennial grass with long creeping rootstalks, is one of the world's best sand-binders. It is propagated readily by division, and once established forms clumps which discourage further movement of sand.

Planting is usually done in the late fall when continued rainfall in sufficient quantities to establish plant growth may be expected. A mulch of cut brush or straw may be spread over the area to



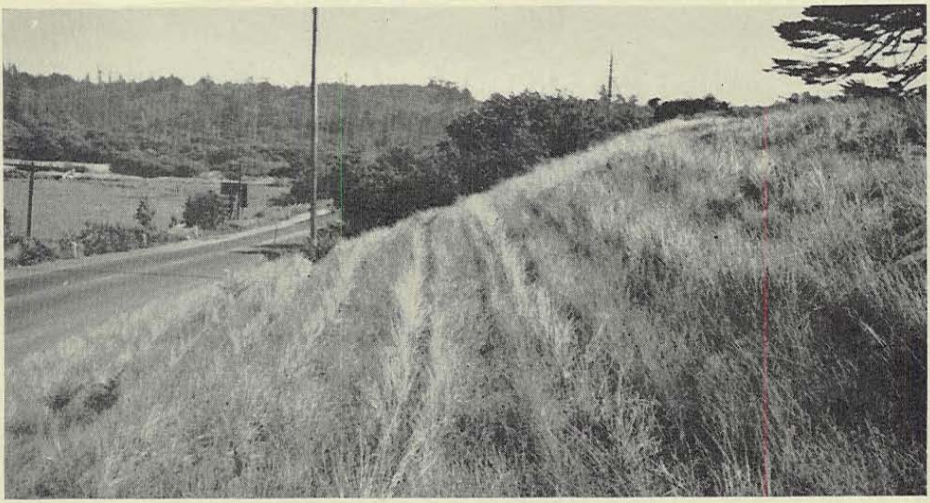
Rock placed by hand on sandy cut slope face, controls wind erosion in desert areas. (Near Little Lake, Inyo County)



A sandy slope, completely stabilized with cut brush and European Beach Grass (Near Pescadero, San Mateo County)

be stabilized in order to stop movement of sand until vegetation becomes established. Divisions of beach grass are then planted through the mulch into moist sand to a depth of about eight inches. If sufficient moisture continues to be available, growth is reasonably rapid, and by the end of the first season the stand of beach grass is usually sufficiently dense to afford effective control.

If sand movement is not too vigorous, the mulch treatment is often not necessary. Divisions of beach grass may be planted in the sand, and if this planting is supplemented by seeding with Italian ryegrass or a cereal grain, satisfactory control may be obtained.



European Beach Grass interplanted with Italian Ryegrass controls wind erosion on a sandy slope. (North of Eureka, Humboldt County)

SEEDING AND GROUND COVER PLANTING

RECORDS LEFT by early-day explorers and missionaries indicate that in their time wildflowers covered the State of California from one end to the other. Few of the annuals and perennials now referred to as native because they have made themselves so thoroughly at home here, had as yet been introduced. Rapidly, however, seeds of new plants were brought in—some as impurities in crop seed, some in the wool or hair of imported animals, some in ship ballast, and some deliberately for forage or agricultural purposes. Finding the climate and soil to their liking, hundreds of these introduced plants became naturalized, and the more aggressive among them literally crowded out the true natives.

The point has now been reached where introduced plants make up the greater part of our herbaceous vegetation. Among these naturalized plants are a number which have been declared noxious weeds because of their growth habits, spiny or prickly nature, difficulty of control, or poisonous effect on livestock, and these must be eradicated on highway rights of way in agricultural areas. Consultation with the local county agricultural commissioner in regard to weed control and seed quarantine regulations is advisable before sowing seed of untested plants in order to avoid introduction of still another pest which would add to our weed control list.

Trial plantings of many varieties of grasses and forage plants have been made for soil stabilization purposes, but for the most part results have been unsatisfactory.

Perennials Unsatisfactory

Perennials are often difficult to establish and, even though a good stand may be obtained, too few plants usually survive the summer drought to provide effective protection the following year. With the exception of Italian ryegrass, also called annual ryegrass *(Lolium multiflorum)*, which grows as a short-lived perennial and naturalizes well

A well-vegetated cut slope. Native shrubs are rapidly becoming established. (Near Watsonville, Santa Cruz County)

Barley and weeds growing on a recently stabilized slope. (Near Monterey, Monterey County)

along the north seacoast, and alfalfa, which persists in a few locations where conditions are to its liking, the perennials so far tested offer no advantages which would prove them superior to annuals for our purpose.

Bermuda grass is extremely effective for soil stabilization in milder sections of the State, but it reseeds so freely and is so difficult to eradicate when once established that it has become a serious agricultural problem in Southern California and the Central Valleys. Public reaction to its use in general highway planting would be immediate and unfavorable. Consequently, Bermuda seed is planted only in localities where the grass is already so thoroughly established that further planting cannot be considered the introduction of a weed pest.

Annuals Effective

Annuals are usually effective during the first year but, except for a very few varieties in favored locations, do not seem to reseed themselves well. Native annuals eventually take over anyway, and since they will offer adequate protection when once established, the naturalization of introduced annuals is not considered too important.

If it were possible to economically obtain seed of the native annuals through commercial channels, a more rapid establishment of a permanent cover could possibly be obtained by sowing this seed during the first year. Neither the quantity of seed available nor the cost makes this procedure practicable, however, since annuals of the type most valuable for stabilization purposes are not useful otherwise, and seed is not harvested commercially.

The conclusion has been reached that almost any annual plant, seed of which is cheap, easy to obtain, and germinates quickly with the first fall rains, will act as a nurse crop and afford adequate and immediate protection. During the first year, and to a greater extent the second year, natives appear, germinating from seeds present in the topsoil or from windblown seeds which have been caught and held by the stalks and stubble of the nurse crop. A sparse growth of the introduced annual will probably volunteer the second year, and the protection given by the combination of growing plants, root mats

and straw remaining from the previous season's growth, is usually complete.

Since barley is harvested in many sections of the State, is about the cheapest seed on the local market, is easily obtainable, and has the virtue of germinating quickly after a light rain even when not covered by earth, it has been most frequently used for stabilization planting. Rye grain, oats, and vetch have also been used successfully.

Grain seed is usually sown broadcast on the rough and uncompacted surfaces of the freshly made or topsoiled slopes, and harrowing or dragging the soil to cover the seed under these conditions has not proved necessary. In the event rain falls before seeding can be done, it is necessary that the slope be cultivated to loosen the surface. Barley and other large-size cereal grains are sown at the rate of one pound per 200 square feet, a considerably heavier rate than that used by a farmer when seeding for grain production.

Quantities of wildflower seed have been sown on highway roadsides for purely ornamental purposes, but this practice has been largely abandoned except on recently completed freeways where sprinkling systems are installed. The successful establishment of a good stand of wildflowers from seed is so dependent upon rainfall conditions in unirrigated areas and the cost of the seed is so relatively high that it is difficult to consistently show results justifying the expenditures.

Poppies Not Lasting

When a roadside project is completed at the proper time of year, California poppy seed is often sown on the new slopes. Given an even start with the weeds and grasses, the poppies will generally grow in sufficient quantity to give a colorful appearance the first season, but slowly disappear thereafter except in rare instances.

Seeds of shrubs and trees have been sown on treated slopes with some success. Spanish broom *(Spartium junceum)*, California wild buckwheat *(Eriogonum fasciculatum)*, silvergreen wattle *(Acacia decurrens dealbata)*, *Encelia californica*, and plume albizzia *(Albizzia lophantha)* seem to germinate well, and since seed is easily gathered from established stands, some use has been made of these plants.

The selection of evergreen ground cover plants for unirrigated areas is extremely restricted. Ice plant or Hottentot fig *(Mesembryanthemum edule)* is most frequently used along the coast and is very nearly the ideal ground cover plant, since it spreads by runners which root at every node, makes a dense mat which discourages weeds, is not a fire hazard, is propagated cheaply and easily by cuttings which root in from 5 to 10 days, bears attractive flowers, is drought resistant, and is not seriously affected by pests or diseases. It does not spread by seed, and is very effective in controlling erosion.

Ice Plant Use Restricted

Established stands of ice plant growing in soils of low fertility tend to die out or become unthrifty after several years. When this condition is not due to lack of soil moisture following a dry season, these patches may be rejuvenated with an application of fertilizer followed by replanting with fresh cuttings.

Since the succulent leaves of ice plant are composed largely of water, the plant cannot be grown successfully in areas where the temperature falls much below the freezing point. This restricts its use in the State to the milder sections where the temperature never falls below about 25 degrees F., and to that point only for short periods.

A roadside planting of Mesembryanthemum edule effectively controls weeds and reduces the fire hazard. (South of Santa Maria)

Other smaller-leaved members of the mesembryanthemum family are slightly more resistant to frost, but do not spread so rapidly as *Mesembryanthemum edule.*

Kikuyu grass *(Pennisetum clandestinum)* has been used as a lawn, and experimental plantings have been made throughout the State. In areas which are subirrigated or which can be given water during the summer, kikuyu grass does quite well. However, it freezes completely back in colder sections and is regarded with suspicion by county agricultural commissioners, who distrust its lusty growth when once established in irigated districts, and consider that it might become an agricultural pest if widely planted.

Successful Plants

Ground cover establishment on freeway slopes and other areas equipped with sprinkling systems is comparatively simple. The following is a list of plants which do not require routine mowing or cutting back and which have been used successfully for this purpose.

SOUTHERN CALIFORNIA

Lantana sellowiana	Trailing Lantana
Lonicera japonica halliana	Halls Japanese Honeysuckle
Hedera helix	English Ivy
Vinca major	Bigleaf Periwinkle
Vinca minor	Common Periwinkle
Ipomoea leari	Dawnflower Morningglory
Fragaria chiloensis	Chiloe Strawberry
Mesembryanthemum—many species	Ice Plant, Figmarigold

NORTHERN CALIFORNIA AND CENTRAL VALLEY

Lonicera japonica halliana	Halls Japanese Honeysuckle
Rosa wichuraiana	Wichura Rose
Rubus ulmifolius inermis	Evergreen Thornless Blackberry
Hedera helix	English Ivy
Vinca major	Bigleaf Periwinkle
Vinca minor	Common Periwinkle
Hypericum calycinum	Aaronsbeard St. Johnswort
Gazania aurantiaca	Gazania

TREE AND SHRUB PLANTING

SINCE MOST of the trees and shrubs planted on highway roadsides are evergreens, they are raised in and planted from containers. Practically no balling is practiced, since the cost of handling and planting balled stock is considerably greater than with stock in containers.

One-year-old plants in one-gallon cans are planted preferably at the start of the rainy season, mulched, and watered during the first summer, then left to themselves except in the very arid regions where they must be watered until well established.

The cheapest and so far the most effective method found for establishing plants in the field consists of planting very young plants in plant bands. Plants from seed started in July are pricked out into 2 inch x 2 inch x 4 inch wooden plant bands set in a nursery flat. By October or November, roots have grown to the bottom of the band, and the plants, 2 inches to 4 inches high, are ready to be set out. In the field, a hole is dug just large enough to take the plant band and the bottom of the hole is flattened and firmed with a wooden block so that air pockets will be eliminated and roots at the bottom of the band will contact the soil evenly. The plant, band and all, is set carefully into the hole, and moist soil firmed gently around it to the level of the soil inside the band. A small quantity of water is then used to settle the earth and moisten the root area, a mulch of straw or manure is applied, and the plant normally receives no further attention. A survival rate of 80 percent is not uncommon.

This method has several distinct advantages. The cost of raising the plants, transportation and planting is considerably less than for larger plants; therefore, many more plants can be planted. Maintenance cost is reduced or eliminated, since the small plants grow like seedlings and require no staking or trimming. Any plants which die can be replaced the following planting season for less money than it would take to water them during the summer. Since root development has not been restricted while in the plant band, normal root growth takes place in the soil outside the band almost immediately after planting. The planting operation involves no disturbance of the root system; therefore, the plant is not set back and growth continues without a pause.

Several precautions must be observed when handling planting stock in bands. The young plants should be planted as soon as the roots appear at the bottom of the band. If planted sooner the roots are dependent entirely upon the moisture contained in the soil within the band itself, and since lateral penetration of moisture through the wooden-band walls seems to be very slow, soil surrounding the roots within the band dries out rather quickly and the plant suffers. If planting is too long postponed after the roots appear at the bottom of the band, the plant is likely to become stunted or suffer a setback when roots are broken during removal of the band from the flat, and the natural tendency of the roots to grow downward may be discouraged. Earth must be moist and firmed evenly in the bottom of the planting hole in order that the roots may penetrate immedi-

Planting small Eucalyptus rostrata in plant band

ately and draw moisture from the outside soil. If moisture conditions in the soil surrounding the plant band are favorable, the plant requires no further watering.

Nursery operations must be closely coordinated with field planting operations in order to insure that plants are planted when the roots are in the proper stage of development. If plants are growing vigorously, this period lasts no longer than two or three weeks.

Growth obtained 28 months after planting. (Between Colton and Ontario, Riverside County)

Plants which have been handled successfully in plant bands include:

Eucalyptus—many species	Eucalyptus
Eriogonum	California Buckwheat
arborescens	Island Eriogonum
fasciculatum	Flattop Eriogonum
Acacia longifolia	Sydney Acacia
dealbata	Silvergreen-Wattle Acacia
pycnantha	Goldenwattle Acacia
Photinia arbutifolia	Toyon, Christmasberry
Rhus laurina	Laurel Sumac
Hedera helix (as established cuttings)	English Ivy
Lonicera japonica halliana	Halls Japanese Honeysuckle
Spartium junceum	Spanish Broom, Weaversbroom
Baccharis pilularis	Chaparral Broom, Kidneywort Baccharis
Lavatera assurgentiflora	California Treemallow

and many others.

Cuttings of any of the many species of willow are planted in wet or seepage areas, where the roots tend to restrict movement of saturated soil, and the moisture transpired by the leaves helps to dispose of surplus water.

Baccharis viminea cuttings are frequently planted on fill slopes in the mountains of Southern California where storms of high intensity make elaborate erosion control measures necessary. These cuttings 18 inches to 24 inches long and from ⅜ inch to 1 inch in diameter, are made in the late fall and early spring of the year and are planted right-end-up in moist soil as deeply as possible, preferably with only 3 inches or 4 inches of the cutting left exposed. If the soil is hard, a slender bar must be used to form the planting hole in advance of placing the cutting; but if the soil is saturated, the cutting may be thrust into the wet bank to the proper depth without damaging buds or bark. Roots are formed within a few weeks, and the plant makes a remarkable growth, sometimes sending up shoots 6 feet to 8 feet high the year following planting.

Willows planted in moist areas assist in stabilization. (Near Watsonville, Santa Cruz County)

Growth made by Baccharis viminea four months after planting as cuttings. (City Creek Road, San Bernardino County)

FIRE HAZARDS AND EROSION CONTROL

SINCE THE long dry summer season in California is unfavorable for the growth of perennials, most of the herbaceous vegetation found along our roadsides is annual in habit. Annual grasses predominate, and since these grasses die down in early summer when the soil moisture is exhausted, a mat of dry vegetation is formed which is extremely inflammable. A carelessly thrown cigarette or match, glowing bits of carbon from a faulty muffler, or even sunlight shining thorugh a discarded bottle or bit of broken glass may start a fire which can do considerable damage.

The consequences of a roadside fire are often serious. Not only are trees and brush damaged or destroyed on the highway right of way, but adjoining crops, pasture or forested land may be burned. Smoke blowing across the traveled way may cause serious traffic accidents. Accelerated loss of soil due to the destruction of the protective vegetation may be expected during the following rainy season.

State Responsibility

The principle has been well established that the State is not responsible for damage caused to adjacent property by accidental fires started on highway right of way, but a certain moral obligation to the public is recognized. In line with this obligation, and often at the request of federal and state agencies, the State undertakes certain fire-hazard-control work, which is essentially the establishment of a control strip of growth-free soil as near to the maintained roadside shoulder as physical conditions permit. This strip, from three to six feet or more in width, may be established either by mechanical methods (disk or grader), or by spraying and burning before surrounding grass will burn (diesel oil), or by soil sterilization (sodium chlorate or chlorate-borate).

It is apparent that if a strip of soil on cut banks or fill slopes is denuded of vegetation, it will be acted upon by the erosive forces of wind and water. Some

Dry vegetation means that fire hazard is high. (Near Bradley, Monterey County)

soil loss is probable. A decision must be made, therefore, as to which is more important: the potential damage which could be caused by a roadside fire which may never start or which might not be controlled by a strip firebreak, or the more certain but less spectacular loss of soil with its attendant maintenance problems. It is a difficult decision to make, since only probabilities are involved, and no one can be certain where or when fires will start or predict the intensity of the rains.

From an erosion control standpoint, and accepting the fire-hazard-control strip as a more or less necessary evil, the "spray and burn" method of denuding the strip seems preferable to soil sterilization. If this method is used, vegetation grows in the strip during the win-

Fire-hazard-control strip formed by the "spray and burn" method. Note the quantity of unburned stems left on the slope after a quick burn. (Near Castroville)

Fire-hazard-control strip formed by the soil sterilization method. Note beginning of soil loss on slope which had previously been stable. (Near Paso Robles, San Luis Obispo County)

ter season and offers some protection to the slope during the rains. Early in summer before the annuals have died, the strip is sprayed with diesel or an inflammable weed oil high in aromatics, then above-ground growth is burned. The root mat remains below the surface of the soil, and assists in stabilizing the slope until fall rains start the cycle anew.

Soil sterilization on cut and fill slopes, on the other hand, results in year-round suppression of plant growth with resultant lack of protection to the slope at any season. This method has the advantage of remaining effective for several years after application, which means a lower yearly cost for treatment, but slopes so treated show a progressively greater soil loss than slopes which are sprayed and burned. Soil sterilization certainly has a place in suppression of plant growth immediately around guide posts and guard rails and in flat areas not subject to erosion, but should be used very judiciously on slopes which may erode.

Mechanical methods of establishing the control strip seldom complicate the erosion control problem, since equipment can operate efficiently only on relatively flat areas, and slopes are usually not disturbed.

Erosion control treatment of newly formed slopes which involves the use of a straw mulch admittedly increases the fire hazard, but the probability of soil loss is so much greater than the possibility of fire damage that the risk is considered justified. Many miles of new highways bordered by straw-covered slopes have been used by the public for the last several years with remarkably little loss due to fire. It is only after the new slopes have become reasonably well stabilized that establishment of a control strip is considered.

Science may one day discover a fireproofing chemical which will be so cheap and so easily applied that it will be practical for roadside use. Unsightly burned strips would then never mar the scenery, and the slight but inevitable differences of opinion between the erosion-minded and the fire-hazard-conscious agencies would be a thing of the past.

MAINTENANCE OF EROSION CONTROL WORK

There is a certain tendency among highway maintenance crews to consider that slope stabilization treatment applied during construction will adequately protect the slopes without further attention. Unfortunately, this is not the case. No form of vegetative erosion control has yet been found which is so effective that some degree of follow-up treatment does not prove to be necessary before the slope can be considered completely stabilized.

The function which a straw covering performs is to restrict or prevent movement of soil particles. As long as no soil particles are moved, rills or gullies cannot form on a well smoothed slope. Lacking rills or gullies, runoff water is not concentrated in a single channel, but moves slowly and evenly to the bottom of the slope.

Once the surface protection of straw is broken, however, soil particles move and small rills form. These rills intersect and form small gullies, which, in turn, act as tributaries to larger gullies, and so on. As the depth of the gullies increases, the area from which they gather runoff water also increases, and the volume of water which appears in the largest gully of a developed system during a light rain is often surprisingly great.

It is obvious, then, that any break in the straw covering must be repaired before soil movement begins in order to take advantage of the protection which the straw blanket is capable of giving.

Frequent inspections, especially during the critical first year, must be given the treated slopes. A sharp lookout must be kept for developing gullies, and additional straw spread in the critical areas before the gullies develop to the point where they become serious. Far better control may be obtained by

Gullies formed in a topsoiled slope by successive rains will increase in depth unless treated. (North of Santa Barbara)

Damage caused by runoff water from adjacent property. (Near Goleta, Santa Barbara County)

using a flake of straw at the right time—while the gully is still small—than by using several tons of straw after the damage has been done. Supplementary seeding of weak areas must be carried out if it is apparent that the original seeding is not giving the protection desired. Cuttings of willow or *Baccharis viminea* should be planted in moist or unstable locations in order to dissipate excessive moisture or to assist in stabilizing potential slide areas. If the straw covering has been disturbed by fire or animals or by some other means, it must be replaced in order that the surface protection may continue to be effective.

It goes without saying that constant vigilance is necessary in order to prevent streams of runoff water from above from running over the slope face. Clogged culverts or broken or inadequate berms or intercepting ditches may allow a concentrated stream of water to pour down over the slope, forming large gullies very rapidly. Surface protection is of no value, in this event, and gullies of this type often endanger the roadway itself.

Disposal of sloughed material which must be removed from gutters and shoulders presents a very real problem. If this material is dumped over stabilized slopes in order to get it out of sight or out of the way in the simplest possible manner, the stabilization treatment is then rendered worthless, since gullies forming in the dumped material cut through the buried stabilized surface in a comparatively short time. The effect of this erosion carries on to the very bottom of the slope, and sometimes beyond, since deposited eroded material helps to concentrate runoff water in a definite channel. Furthermore, dumping on a slope which has been planted to shrubs and trees effectively contributes to the failure of the planting, and the consequent loss of the investment which has been made in stabilization.

Wet material which is end-dumped from a truck will frequently stand at an angle steeper than 1½:1. This steeper slope can be considered an unstable one, since the 1½:1 angle is that formed naturally by loose soil. When saturated

by further rainfall, the dumped material usually slumps, effectively forming channels of concentration which intensify the control problem. When it is necessary to dump wet material over a slope, every effort should be made, first, to flatten and smooth the slope of the dumped material to 1½:1 or flatter, and, second to stabilize the surface with straw, seed, and cuttings as insurance against future trouble.

It is usually possible to find a disposal area in which waste material can be safely dumped within a reasonable hauling distance on most mountain roads. The upper sides of small fills can sometimes be filled in, making a parking or stopping area for the motorist. Other low spots or gentle slopes can be covered with the waste; and if the slope is gentle enough, no further treatment need be given, except, possibly, seeding for the sake of appearance.

Since any form of slope stabilization treatment represents an investment, often a sizeable one, sound economic practice justifies the expenditure of a proportionate amount to protect the investment. The follow-up treatment described here may be carried out so cheaply and so effectively, *if done at the right time*, that its justification should never be questioned.

PART III

DETAILED METHODS OF EROSION CONTROL

TYPE A STABILIZATION FOR STEEP SLOPES

An elaborate method for stabilizing steep slopes was developed to suit special conditions sometimes found on our metropolitan freeways. (*See Slope Stabilization Detail Sheet.*) In highly developed urban areas the cost of purchasing a wider right of way to allow for the construction of flatter slopes may be excessive. In this event, the expense involved in installing this type of stabilization treatment, though high, is justified in that a considerable net saving in expenditure of highway funds is possible.

Some concern has been expressed regarding the permanency of the wooden grid, since no preservative treatment is given the frame members. This method has been in use since 1939 on the Arroyo Seco Parkway in Los Angeles, and no failures due to rotting or weakening of the grid have taken place. It is probable that ground cover plant roots have by this time so permeated the soil that the supporting effect of the wooden frames is no longer required.

Since the areas given Type A Stabilization treatment are invariably covered by a sprinkler system, a rapid and lush growth of ground cover plants

Type A stabilization during construction. Topsoil is cast on by dragline. (Seventh Street Interchange, Santa Ana Freeway, Los Angeles)

Established ground cover planting on Type A Stabilized 1:1 cut slopes. (Arroyo Seco Parkway, Los Angeles to Pasadena)

takes place soon after installation. Periodic applications of commercial fertilizer are made in order to keep the plants growing well, and an occasional clipping or mowing to remove excess or old growth has been found to be necessary.

The only failures experienced on the Arroyo Seco Parkway installations of Type A Stabilization resulted from uncontrolled and concentrated drainage water from areas above, which caused narrow and confined washouts. Also, at bridge abutments where the backfill was not thoroughly compacted, loss occurred when that particular area was overwatered immediately following installation of stabilization.

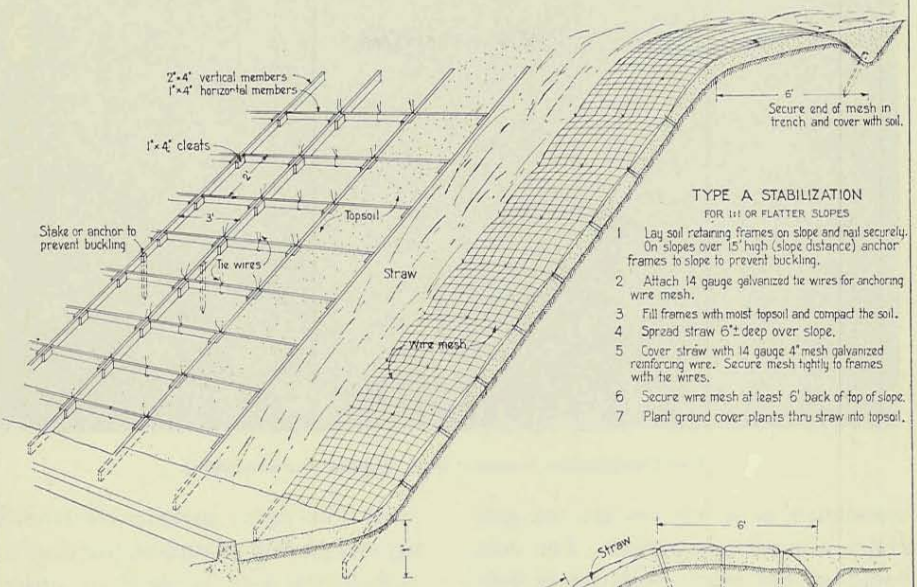
The cost of installing Type A Stabilization, based on bids received in February, 1948, is about $1.45 per square yard. This figure also includes the cost of furnishing and placing topsoil in the frames. Ground cover plants will add about $0.05 per plant, or if planted 12 inches apart, $0.45 per square yard to the above cost.

TYPE B STABILIZATION FOR CERTAIN 1½:1 SLOPES

THIS METHOD for stabilizing 1½:1 or flatter slopes was developed for use on urban freeways in locations where any soil loss whatever could result in a traffic hazard. (*See Slope Stabilization Detail Sheet.*) A slope which is constructed at the top of a retaining wall or which is close to adjacent improved property must be positively controlled, since damage claims or danger to the traveling public could result if any portion of the slope failed. A thick layer of straw held firmly in place by anchored strips of wire mesh effectively prevents the two types of soil movement—surface loss and slippage. After vegetation has become established, permanent stabilization is a reality.

This procedure, while extremely effective, is too costly for general use on rural highway roadsides where the

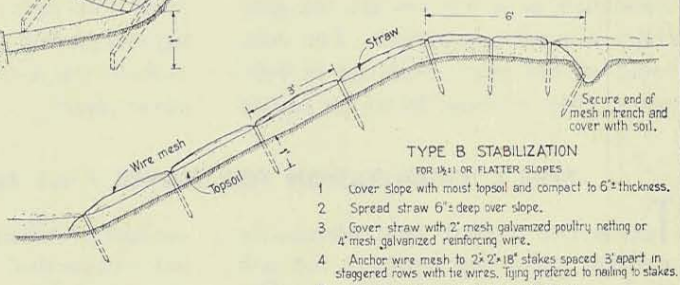
SLOPE STABILIZATION



TYPE A STABILIZATION

FOR 1:1 OR FLATTER SLOPES

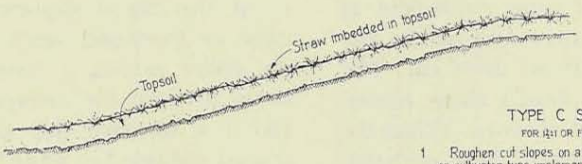
1 Lay soil retaining frames on slope and nail securely. On slopes over 15' high (slope distance) anchor frames to slope to prevent buckling.
2 Attach 14 gauge galvanized tie wires for anchoring wire mesh.
3 Fill frames with moist topsoil and compact the soil.
4 Spread straw 6"± deep over slope.
5 Cover straw with 14 gauge 4" mesh galvanized reinforcing wire. Secure mesh tightly to frames with tie wires.
6 Secure wire mesh at least 6' back of top of slope.
7 Plant ground cover plants thru straw into topsoil.



TYPE B STABILIZATION

FOR 1½:1 OR FLATTER SLOPES

1 Cover slope with moist topsoil and compact to 6"± thickness.
2 Spread straw 6"± deep over slope.
3 Cover straw with 2" mesh galvanized poultry netting or 4" mesh galvanized reinforcing wire.
4 Anchor wire mesh to 2"×2"×18" stakes spaced 3' apart in staggered rows with tie wires. Tying prefered to nailing to stakes.
5 Plant ground cover thru straw into topsoil.
6 If slope is to be seeded sow seed before placing straw.



TYPE C STABILIZATION

FOR 1½:1 OR FLATTER SLOPES

1 Roughen cut slopes on a rough contour with a scarifier or cultivator type implement in a series of longitudinal grooves or corrugations.
2 Cover cut slopes with 3"± to 6"± of topsoil. If topsoil is not available cultivate slope 4" to 6" deep and apply fertilizer. Fill slopes will not ordinarily require topsoil or cultivation unless very sterile or compacted.
3 Cover slope with straw at rate of 4± tons per acre. Imbed straw into loose soil with a sheepsfoot roller.
4 Plant ground cover thru straw into topsoil.
5 If slope is to be seeded sow seed before placing straw.

PREPARED BY
LANDSCAPE SECTION OF THE DESIGN DEPT.
CALIFORNIA DIVISION OF HIGHWAYS

MRB - 8-27-48

Type B stabilization treatment ready for ground cover planting

consequences of soil loss are not generally immediately serious. The cost, based on bid prices received in February, 1948, is about $0.90 per square yard. This figure includes the furnishing and placing of topsoil, but does not include the cost of seed or ground cover plants.

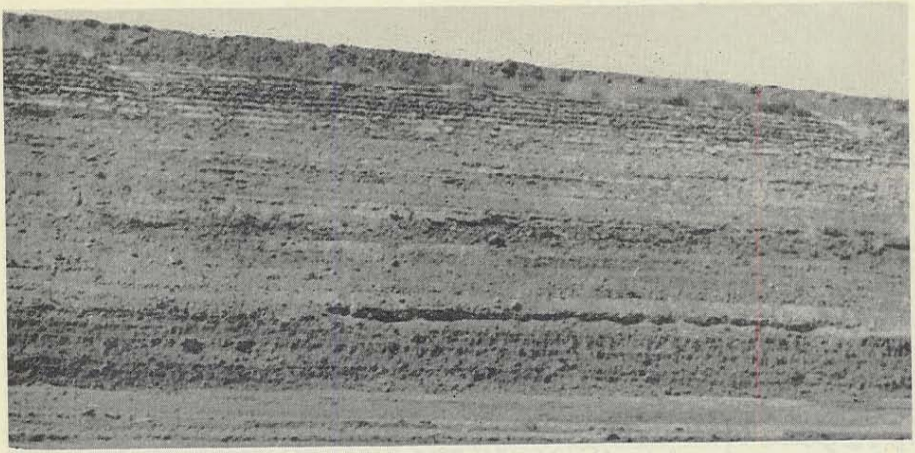
TYPE C STABILIZATION FOR SLOPES 1½:1 AND FLATTER

THIS IS THE method most commonly used for stabilizing highway cut and fill slopes. (*See Slope Stabilization Detail Sheet.*)

Cut slope roughening, to be most effective, should be done with a scarifier or cultivator type implement as excavation progresses and before the newly exposed subsoil dries out. The roughened slope should show corrugations on a rough contour. When the soil becomes saturated, these corrugations tend to break up the smooth slippage plane which forms between the layer of topsoil and the relatively impermeable subsoil.

Maximum compaction of the surface layer of soil by rolling with a sheepsfoot roller can only be obtained when the soil contains the optimum amount of moisture, as determined by soil compaction tests. Normally only one round trip of the roller is required, though additional rolling may be done if it appears that a greater degree of compaction would be desirable. In this event, the rate of application of straw must be increased, since each pass of the roller presses a small amount of straw beneath the surface of the soil, and it is essential that enough straw remain unburied to afford surface protection.

Experience has revealed that on 1½:1 cut slopes, there are apt to be fewer failures during the first heavy rains if the topsoil blanket is restricted to approximately two inches to three inches in thickness. Thicker coverage tends to saturate, become heavy, and



Well roughened cut slope ready to be topsoiled

slip. As the degree of slope lessens, the depth of the layer of topsoil can be increased if desired.

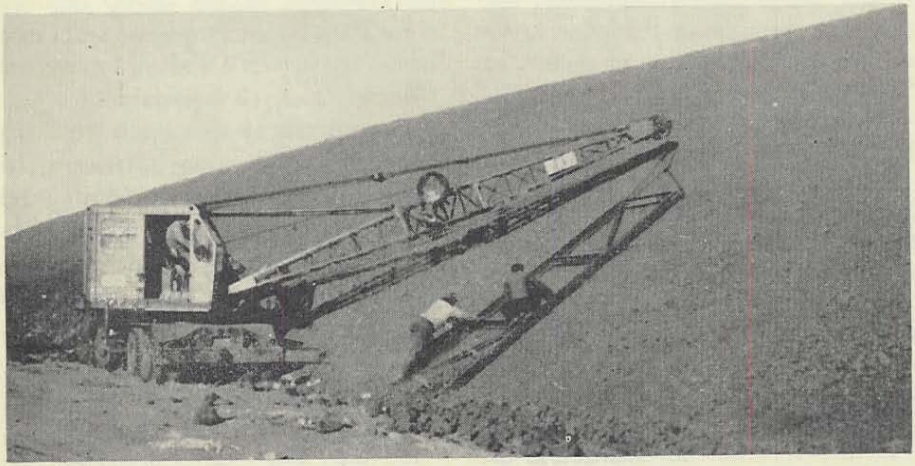
The cost of Type C Stabilization, based on a number of 1948 and 1949 bids, averages as follows:

Slope preparation or roughening	$0.08 per sq. yd.	$387.20 per A.
Straw at 4 tons per acre	55.00 per ton	220.00 per A.
Total		$607.20 per A.

Add the cost of seed or ground cover plants.

The price paid per ton for straw includes the cost of furnishing, spreading and rolling. The cost of handling and spreading topsoil does not appear, since this item is included in Roadway Excavation quantities, and is paid for as such.

Commercial fertilizer, to be applied at the rate of 30 pounds to 40 pounds per 1,000 square feet averages about $85 per ton. A complete fertilizer having an analysis of 6-9-6 or 6-10-4 is usually specified.



Spreading and smoothing topsoil on a roughened slope

Spreading straw on newly topsoiled slope

BRUSH LAYER METHOD FOR STABILIZATION OF EXTREMELY ERODIBLE FILL SLOPES

THIS METHOD was developed for use during construction in stabilizing fill slopes composed of erosive soils in regions where rainfall intensities are high. The function of the brush layer is to minimize formation of gullies, in the event the surface protection fails, by dispersing the stream and reducing the velocity of the runoff water.

In order to simplify the detail sheet, the term, "Brush Layer," has been used throughout the specification, though actually other materials have, at times, been used for this purpose. These variations are discussed below.

In addition to the installation of brush layers or mats, this method differs from Type C Stabilization procedure in that a heavier application of straw and additional rolling with a sheepsfoot roller are specified. Excellent compaction is obtained below the outer 2 inches by thoroughly rolling each portion of the slope, and the comparatively uncompacted outer two inches are so mixed with straw that the tendency to wash is minimized.

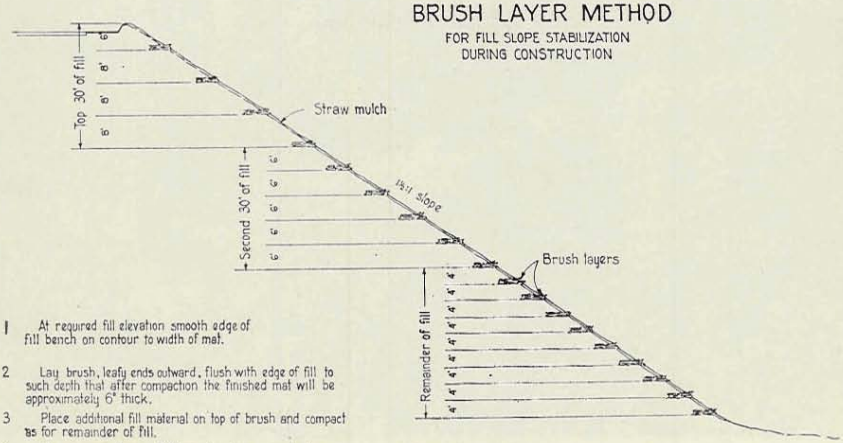
Our specifications require that the complete stabilization treatment be given fill slopes at stages during fill construction in order that no extensive area of unprotected slope shall be exposed to damage from unseasonal cloudbursts which sometimes occur in the mountains of Southern California.

When brush is not readily available, at least two alternatives are possible:

1. *Straw Mat.* Lay 1-inch-mesh galvanized netting or fencing on the pre-

BRUSH LAYER METHOD

FOR FILL SLOPE STABILIZATION
DURING CONSTRUCTION



CROSS SECTION

1 At required fill elevation smooth edge of fill bench on contour to width of mat.

2 Lay brush, leafy ends outward, flush with edge of fill to such depth that after compaction the finished mat will be approximately 6" thick.

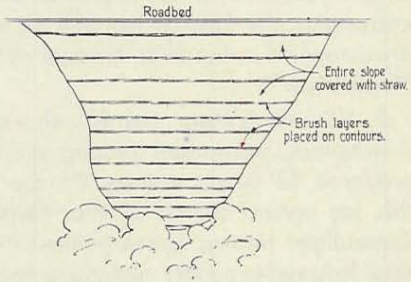
3 Place additional fill material on top of brush and compact as for remainder of fill.

4 At convenient stages of fill construction spread straw evenly over slope at rate of *4 tons per acre. Roll with a sheepsfoot roller operated vertical to the plane of the slope until straw is thoroughly incorporated into the soil. At least 4 round trips of the roller will be required.

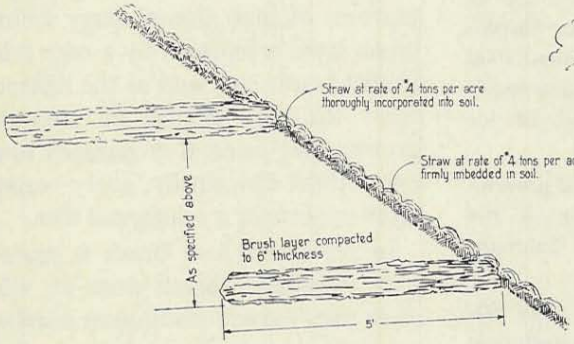
5 Sow evenly over the slope a mixture of 50% Barley, 45% Rye grain and 5% Alfalfa seed by weight at rate of 200 lbs. per acre.

6 Spread second application of straw at rate of *4 tons per acre. Repeat rolling operation until straw is firmly imbedded in soil.

7 Plant live cuttings of Baccharis and Willow, or cuttings and seed of hardy varieties of plants indigenous to the locality, between mats for permanent vegetative protection.



SIDE ELEVATION



DETAIL SECTION

* The total quantity of straw applied per acre will vary according to the character of the fill material. Loose, granular, disintegrated granite soil usually requires more straw per acre for an adequate cover (6 to 10 tons per acre) than does soil of a loamy character (4 to 8 tons per acre).

MRB 5-21-47

Brush layers and wire reinforced brush mats installed in a fill during construction. These mats have been allowed to protrude too far. Note rock protection at toe of slope. (City Creek Road, San Bernardino County)

pared fill bench surface. The mesh should extend into the fill about five feet. Spread straw on the mesh to such depth that after compaction the finished mat will be approximately 4 inches thick. Proceed as for "Brush Layer."

2. *Wire Mesh Mat.* Lay 60-inch-wide, 4-inch-mesh, galvanized fencing on the prepared fill bench surface. On top of this, lay several courses of War Surplus Camouflage Netting (green-painted steel wool fastened to poultry netting), or small-mesh poultry netting. Proceed as for "Brush Layer."

A more elaborate, denser, and presumably structurally stronger form of the Brush Layer has been used in Southern California:

Wire Reinforced Brush Mat. Lay 60-inch-wide, two-inch to four-inch-mesh galvanized fencing on the prepared fill bench surface. Place brush on wire, leafy ends outward, to such depth that after compaction the finished mat will be from four inches to six inches thick. Lay wire mesh on top of brush and tie edges together at one-foot intervals with 16-gauge galvanized wire. Tie along center and at quarter points at three-foot intervals. Stake sufficiently to prevent slipping under additional fill. Proceed as for "Brush Layer."

This type of mat may be used in conjunction with brush layers in locations where conditions are extreme.

On low embankments and the upper portions of high slopes, every fourth brush layer is replaced by a wire reinforced brush mat, and as the distance from the top of the fill becomes greater, this interval is reduced until every third and, finally, every second layer consists of a reinforced mat.

In sections where brush is scarce, wire reinforced brush mats or wire mesh mats have recently been installed at 15-foot vertical intervals in low embankments and the upper portions of high embankments, and at 10-foot vertical intervals in the lower portions of the high slopes. No intermediate brush layers were used in these sections.

When wire mesh or fencing is used, the outer edge should be laid far enough inside the ultimate slope line that it will not be damaged during the rolling operation. Lengths of fencing should be overlapped and fastened together in order to take advantage of any structural strength and resistance to slumping which the wire may offer. The wire mat may then extend continuously for the full length of the fill, plus a short distance beyond the intersection of the embankment slope and original ground where it should be secured.

The interval between brush layers or mats as shown on the detail sheet is not critical, and may be increased or decreased to suit variable soil and climatic conditions.

It has now become standard practice to supplement this elaborate type of slope protection treatment with a planting project which is carried on concurrently with the construction contract. During the season when enough moisture is present in the soil to support plant growth, state forces plant cuttings of Baccharis or willow and seed and plants of suitable shrubs and trees on fill slopes as soon as the slope treatment is completed. This procedure has proved much more satisfactory than inclusion of the planting as a contract item in the construction contract, since the day labor work order under which the work is financed can be extended beyond the contract completion date, and the work may, therefore, be suspended if planting conditions are not favorable.

It should be emphasized here that the establishment of an adequate growth of permanent trees and shrubs to reinforce the relatively short-lived Baccharis and willow planting is highly desirable in localities where soil type and rainfall intensity justify these elaborate control measures. Tree and shrub roots, penetrating the fill material, consolidate and bind it to a degree obtainable by no other means, and by the time brush layers rot or wire rusts away these roots are capable of holding the soil firmly in place. Thus, truly permanent control can be established.

Rolling 10-foot strip of fill slope after application of straw. (City Creek Road, San Bernardino County)

The average cost of these various methods, based on 1947, 1948, and 1949 bids is as follows:

	Per lineal foot
Brush layers	$0.17
Wire reinforced brush mats	$0.50
(One contractor stated his actual cost was over $1 per lineal foot.)	
Wire mesh mats (camouflage netting)	$0.55 to $0.75
(The State furnished war surplus camouflage netting at no cost to the contractor for these mats.)	
Wire mesh mats (poultry netting)	$1.15
Straw mat: No costs available.	

Straw, furnished and spread on the slopes in two applications at the total rate of six tons per acre, averaged about $64 per ton, or $384 per acre. The cost of rolling or compacting slopes, which was set up as a separate item on these contracts, ranged from $0.08 to $0.12 per square yard, or $387.20 to $580 per acre.

STRAW OR BRUSH WATTLE METHOD

This is an early method used for stabilizing fill slopes after construction. Fair control was obtained with this method, but it has several distinct disadvantages.

All operations must be done by hand labor. This means that unless a cheap source of labor is available, such as a prison road gang, a CCC crew, or WPA or its equivalent, the labor cost is so high as to make the cost of installation prohibitive.

Wattles installed in trenches intercept and hold runoff water. No further runoff can take place until the trench is filled with water to the overflow point. This condition cannot help but result in saturation of the uncompacted soil around and below the wattle, with consequent undermining or slumping and failure during storms of high intensity.

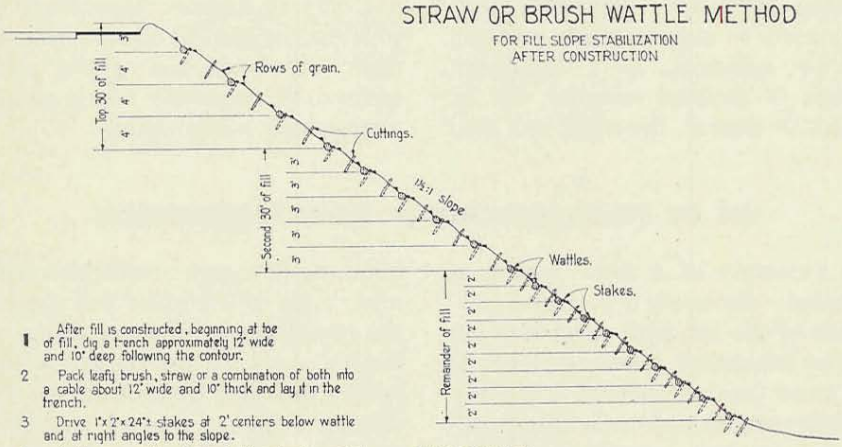
ROCK METHOD FOR FILL SLOPE STABILIZATION

An effective method used where practicable for mechanically stabilizing fill slopes involves the use of rock. In locations where excavated material containing sound rock is available within a reasonable hauling distance, chunks of rock, the larger the better, are placed in the outer portion of the embankment as the fill is made. Portions of the embedded rocks protrude from the fill surface. Since the rocks themselves are not subject to erosion, the possibility of damage is confined to the intervening spaces where the finer surface material is exposed. This vulnerable area may be reduced or even eliminated if enough rock is available to overlay the slope surface completely. In addition to offering protection from surface erosion, the embedded stones decrease the tendency toward saturation and slumping which is so characteristic of slopes composed entirely of finer materials.

The degree of vegetative protection required on a rock-treated slope de-

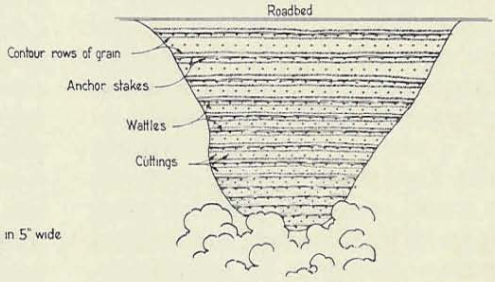
STRAW OR BRUSH WATTLE METHOD

FOR FILL SLOPE STABILIZATION
AFTER CONSTRUCTION

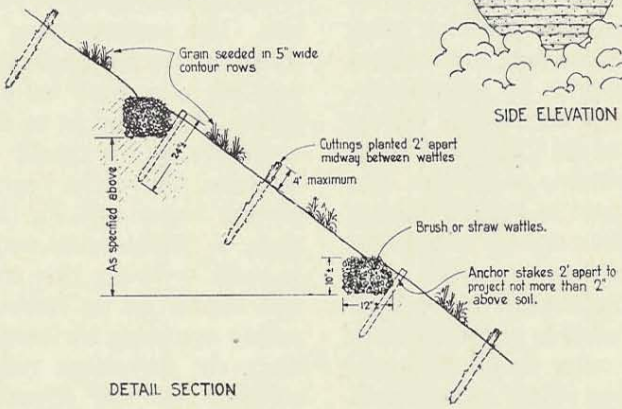


CROSS SECTION

1. After fill is constructed, beginning at toe of fill, dig a trench approximately 12" wide and 10" deep following the contour.
2. Pack leafy brush, straw or a combination of both into a cable about 12" wide and 10" thick and lay it in the trench.
3. Drive 1"x 2"x 24"± stakes at 2' centers below wattle and at right angles to the slope.
4. Partly cover wattle just placed with material excavated from next trench above.
5. After wattles are all placed plant living cuttings not less than 1" in diameter and 24" to 30" long at 2' centers in rows midway between wattles. Set cuttings in the ground until they protrude only 3" or 4".
6. Seed Barley, Rye grain or Alfalfa in 5" wide rows just above and just below each wattle and broadcast additional seed evenly over surface of slope.



SIDE ELEVATION



DETAIL SECTION

pends upon the extent of rock coverage. If very little granular material is visible, seeding plus tree and shrub planting (provided sufficient "fines" are present to support plant growth) will be sufficient. If a significant amount of exposed material will be subject to erosion, the straw and seed method followed by tree and shrub planting may be required. In any event, some planting should be done, not only to improve appearance, but to arrest the gradual downward movement of stones and gravel which seems to be constantly taking place on unvegetated rocky slopes.

USE OF STRAW MULCHES IN SLOPE STABILIZATION

The function of a straw mulch, as previously discussed, is to afford protection to the soil until vegetation has become established. Lasting qualities of the straw are considered relatively unimportant, since after the first growing season plant growth should be sufficiently dense to retard soil movement, and the straw protection should no longer be required. Considerable latitude is, therefore, allowed in our specifications as to the type of straw to be used. Wheat, barley, oat or rice straw are usually specified as choices, although spoiled hay (alfalfa, grain, or wild-grass) would be acceptable provided it was not rotted or extremely brittle. Used stable bedding from the race tracks, consisting of barley straw mixed with horse manure, was obtained at a reasonable price by several contractors and used successfully on the high fill slopes of the City Creek Road in the San Bernardino Mountains. The type of straw used in a given locality is, therefore, governed by availability and price rather than by variety.

Rates of application are related directly to the number of rollings with the sheepsfoot roller which are specified, and the type of soil encountered. Each pass with the sheepsfoot roller presses some of the straw so deeply into the soil that it is no longer visible or effective as surface protection. Highly erosive soils, then, which require the thorough compaction which many trips of the roller will produce, the consolidating influence of the embedded straw and also the surface protection provided by protruding straw, require a higher rate of application than less critical soils.

Ordinarily, an application of four tons of straw per acre is specified. This rate is based upon the quantity of average quality straw of the variety which is most often furnished (in our case, barley) which is required, when evenly spread over a slope acre, to cover the average soil to such depth that after one rolling with a sheepsfoot roller enough straw will remain exposed on the surface to afford protection. The accompanying illustrations show the normal application of four tons per acre both before and after rolling. A rate of six to eight tons of straw per acre is usually specified in locations where the degree of compaction desired calls for from six to as many as twelve passes with the roller, in order to insure that enough straw will remain on the surface after the rolling operation has been completed. Since the sheepsfoot roller will not compact the soil effectively if the straw blanket is spread at an appreciably heavier rate than four tons per acre, the six- to eight-ton covering is spread in two applications, each followed by a thorough rolling.

Short, brittle or very coarse straw does not cover the slope surface so well as new long-stemmed straw; and if only straw of this poorer quality is available, the rate of application should be increased until a sufficiently thick covering is left on the surface after rolling to offer the protection desired.

The unit of measurement, "tons per acre," has been found to be the most practical unit to use. Bales of straw vary both in size and weight, and the unit "inches depth" is too dependent upon whether the straw is stiff or limp or has been baled tightly or loosely.

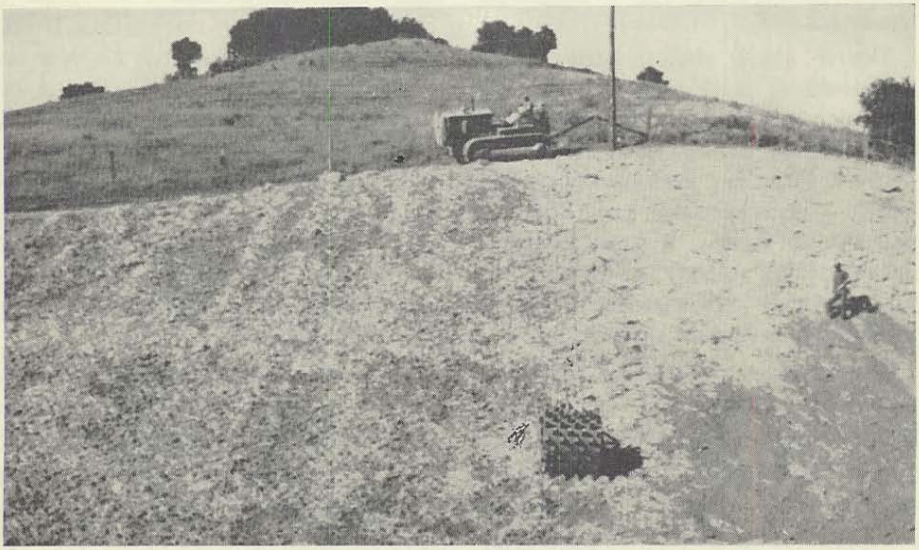
In all cases where slope surface protection areas are involved, the terms "acre" or "square yard" refer to slope measurement.

USE OF SHEEPSFOOT ROLLER IN SLOPE STABILIZATION

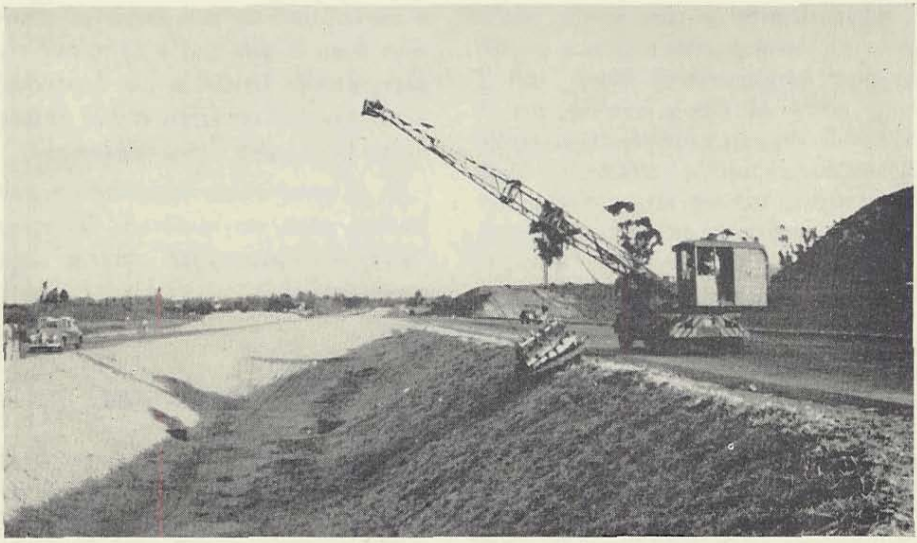
SEVERAL methods have been developed for utilizing a sheepsfoot roller in compacting the slope face and incorporating the straw with the soil.

When rolling 1½:1 and 2:1 cut slopes, a single roller equipped with a yoke has been connected by wire cable to the power-operated drum unit located on the back of a Caterpillar tractor. The roller is lightened of ballast to the point where it will roll down the slope when the cable is slack but is not so heavy as to cause an excessive load on the power unit when being pulled back to the top of the slope.

The tractor is positioned at the top of the slope, broad side to the slope face. The roller is let down, speed of descent being controlled by the power unit brake, then pulled to the top of the slope. After the required number of round trips are made, the tractor is moved a distance equal to the width of the roller and the process repeated.



Spreading straw and rolling 1½:1 cut slope with cable-controller sheepsfoot roller. (Vicinity of Salinas)



Rolling low fill slope after completion of roadway. Roller is towed by the boom cable and held in position by a second cable attached to the uphill side of the yoke. (In this case, straw was applied to protect sand slopes from wind erosion.) (Near Colton, San Bernardino County)

While this method has been most often used for rolling cut slopes, it is also adaptable for rolling embankment slopes, although more roller ballast may be required in order to load the roller to the point where it will roll down the slope of its own weight in the looser soil.

When 1½:1 embankment slopes composed of very loose or granular soil, such as disintegrated granite, are to be rolled, it may be necessary to give the slope one preliminary rolling before straw is spread in order to compact the soil lightly. If straw is spread on very loose soil, the roller tends to push the straw and loose soil ahead of it on the first downward trip.

When straw is spread on the completed portion of a fill slope at stages during construction of the fill, a long arched extension tongue has been used to connect a standard two-section sheepsfoot roller directly to the tractor drawbar. The tractor is backed to the top of the slope, the roller being let down over the edge, and the required number of round trips are made by moving the tractor forward, away from the top of the slope, and back, for a distance equal to the length of the tongue (Page 47).

An advantage of this method is that the tractor and roller may be used for compacting fill material without re-rigging during the period while the fill is being built up to the next stage.

Rolling flatter slopes offers no great problem. Equipment can often work directly on the slope, and a standard two-section sheepsfoot roller hitched directly to a tractor has been used to roll the slope longitudinally.

A truck crane has also been used to roll low cut and fill slopes lengthwise. Two cables are attached to the roller, one to control the position of the roller on the slope and the other to pull it. Care must be taken with this method so that the axis of the roller

is at right angles to the direction of the pull, since a skewed roller has a tendency to pick up straw from the surface of the slope.

High fill slopes can be effectively rolled with a heavily weighted two-section sheepsfoot roller, provided a cable winch of sufficient power and braking capacity is available. A truck crane has proved very efficient for rolling slopes of as much as 300-foot length in the mountains of Southern California (Page 16).

After straw is spread, the roller, connected directly by cable to the winch, is stationed at the top of the slope and allowed to roll to the bottom by its own weight, the speed of descent being controlled by the winch operator. It is then pulled back to the top of the slope and the cycle repeated until the required number of round trips of the roller have been made. The crane boom cable is then hooked to an eye attached to the roller frame, the roller hoisted free of the slope, the truck moved forward a distance equal to the width of the roller, the boom cable unhooked, and the rolling resumed.

REPAIR OF FAILURES ON NEWLY STABILIZED SLOPES

A FEW FAILURES are almost inevitable during the first winter after installation of any type of slope stabilization treatment. The extent and seriousness of these failures is usually directly related to the intensity of the first storm of the season, which occurs before vegetation has started growth and before the soil has become completely consolidated. Prompt and effective repair of sections which have failed is extremely important, since no further loss of soil then takes place and the repaired area becomes stabilized during the remainder of the rainy season.

The most frequently observed type of failure is surface slippage. If the slip starts at the top of the slope or near the top, it is likely that seepage or percolation of water from above

Surface slippage due to saturation caused by a 6-inch rainfall in 24 hours. (Vicinity of Salinas)

through a porous layer of subsoil is causing the damage. This percolation may be intensified by standing water in a poorly graded intercepting ditch or leakage through cracks in a paved shoulder or drainage ditch. Small amounts of runoff water of insufficient quantity to cause gullying may also cause this type of failure. Since saturation in this case is caused by water which originates elsewhere than on the slope face, a necessary preliminary to repair is correction of the defective drainage condition.

Slips which start on the lower two-thirds of the slope, or below, are usually caused by saturation of the soil due to lack of sufficient compaction before the rains start. On cut slopes, insufficient roughening of the subsoil before topsoil is applied sometimes increases the tendency toward slippage. Since this condition cannot be corrected after the slippage has occurred, and since rainfall which has caused the damage has also compacted the portions of the slope which have not failed to the point where further failure is unlikely, corrective operations can be restricted to simple repair.

If failures appear on cut slopes which have been given Type "C" stabilization treatment, the area from which surface soil has slipped need not be backfilled with topsoil as part of the repair process. Sufficient topsoil particles are usually left to support some plant growth, and a replacement layer of topsoil would be subject to the same conditions which caused the original failure. Furthermore, any cultivation of the exposed subsoil is considered unnecessary, since loose soil would then be subject to saturation and possible loss.

The most economical and satisfactory method for repairing surface slips has proved to be fertilization and heavy seeding of the exposed subsoil and the application of a straw mulch, held in place, if necessary, by a few shovelfuls of loose soil. The sooner this method is employed, after failure, the better, since moisture already in the soil will

Sections from which topsoil has slipped were repaired with fertilizer, seed and straw and are now successfully stabilized. (Near Castroville, Monterey County)

Gullies on a 1½:1 topsoil cut slope caused by runoff from adjacent property. An intercepting ditch and downdrain are needed here. (Balboa Freeway, San Diego)

germinate the seed and the straw covering will retard further soil loss. Cereal grain seed is used for this purpose because it will germinate quickly and successfully beneath a straw mulch, is easily obtainable, and is inexpensive. This treatment may be supplemented by planting cuttings of ground cover plants or shrubs.

Extensive gullies sometimes appear on highway slopes, caused by a concentration of runoff water from above due to berm failure, plugged downdrains or inadequate diversion ditches. After the condition causing the concentration of water has been corrected, moderate-sized gullies may be repaired as described above. If the gully threatens the traveled way, backfilling is sometimes necessary, and in this event care should be taken that the backfill material is well compacted during application.

Rills which develop on a recently constructed slope which has not been covered with straw may be treated with seed alone, or straw and seed if the soil appears to be extremely erosive.

Since most of these repaired areas do not fail during the storm following treatment, the necessity for repair work lessens year by year, until complete control is established.

REPAIR OF OLD ERODED SLOPES

Light cultivation of the compacted soil is a necessary preliminary to successful repair of old eroded slopes which do not require rebuilding. If seed is sown on uncultivated and gullied soil, the seed tends to concentrate in pockets in the bottoms of the gullies, and a large proportion rolls to the bottom of the slope and is lost. The cultivating operation creates a more favorable condition for seed germination, and also smooths out irregularities and breaks up channels of concentration in the gullied slope.

Cultivation should be followed by fertilization, seeding and the application of an adequate straw mulch. Thereafter, the slope should be given routine maintenance, repairs being made as soon as failures become evident.

On soil slopes, it has not been found necessary to tie the straw covering down with pegs and twine or wire to prevent serious loss by wind action. In a few days the unsecured straw blanket seems to settle and mat and is then able to withstand winds of considerable velocity without damage. This settling may be accelerated and seed germination hastened by sprinkling the straw with water after spreading. As soon as the seed germinates the straw is held securely in place, so the cost of pegs and ties simply to prevent possible loss of straw between the time of application and the time of seed germination is not considered justified. A large quantity of straw can be replaced for the cost involved in holding the blanket in place mechanically.

Successful repair work on old eroded fill slopes in localities subject to storms of high intensity, as in the mountains of Southern California, is likely to be a long-term proposition. If the seasonal rainfall is favorable during the first year after installation, almost complete control is possible with a treatment consisting of cultivation, fertilization, straw mulch, grain seed and a thick planting of willow or Baccharis viminea cuttings. If heavy storms come before the seed and cuttings have become established, failure of portions of the treated slope can be expected, the extent of failure being dependent upon the intensity of the storm. A continuing program of failure repair is, therefore, necessary until vegetation has become completely established, after which time maintenance activities can usually be restricted to correction of defective drainage conditions as they appear.

Hard, gullied disintegrated granite fill slope. Construction of log and brush crib at toe of slope is first step in repair procedure. (Between Redding and Weaverville, Shasta County)

Brush is placed in gullies before backfill material is spread on slope face. Note log and brush crib at toe of fill

The present-day cost of labor is so high that hand smoothing of slopes and installation of wattles is not considered economically feasible. The less elaborate methods of treatment described above are believed to be as effective in the long run if proper maintenance is forthcoming, and are certainly much cheaper to install than the wattle treatment.

Large gullies or slipouts in fill slopes require more extensive treatment, since it is usually necessary to replace the material which has been lost in order to safeguard the roadbed.

The illustration on Page 56 shows a slope which is so badly gullied that repair is necessary. This soil, when dry, sets up so hard that it is almost impossible to walk on the slope. It is obviously unreasonable to assume that loose soil, end dumped upon a slope like this and given no further treatment, can be expected to remain in place during the following rainy season. Compaction or the utilization of some means of keying the loose backfill material to the slope surface until consolidation has taken place is essential in order to insure effective repair.

If maintenance funds are restricted, and gullies not too large, this repair method can be relied upon to provide control in from two to three seasons.

A crib of logs and coarse brush is constructed at the toe of the fill in order to provide a solid foundation against which backfilled material can settle. Loose brush is then placed in the slope gullies and covered with a moderately thick layer of backfill material. Additional brush is spread over the surface and covered with soil. This process is repeated until the original fill contour is restored. Surface protection of the type justified by the soil and locality is then applied, and seed and cuttings of suitable plants are planted during the following planting season.

Since the backfill material is not compacted by this method, we must expect saturation, settlement and even slumping, to the extent allowed by the

Reworking fill slope face with bulldozer and installing brush layers. (Near Weaverville, Trinity County)

consolidating influence of the buried brush, during the rainy season following treatment. The area affected by this settlement is usually near the top of the treated section, however, and can be backfilled and treated as described above without disturbing the growth of vegetation on the unaffected portion of the slope. A third treatment, following the next rainy season, is sometimes necessary in order to compensate for further settlement of the backfill material, but under average conditions very small areas are involved and the cost is not high.

If gullies are so large and the danger to the roadway so great that the fill slope must be fully restored immediately, the method illustrated here is recommended.

This method involves reworking the entire outer surface of the affected portion from the bottom up. A log and brush crib is first constructed at the toe of the fill to offer a solid foundation against which the soil can be compacted. Backfill material is furnished from the top, and a tractor equipped with a bulldozer is used to spread, compact and shape this material to the original fill contour. Brush layers are installed at suitable intervals as the fill is built up. (See brush layer method detail sheet.) The completed slope is then given surface protection, including a thorough rolling, if possible, and suitable seed, plants and cuttings are planted at the proper time.

CONCLUSIONS

THE MOST successful erosion control methods have proved to be those which reproduce most closely conditions which are to be found on natural slopes. Mechanical or unnatural methods of control, while sometimes immediately effective, deteriorate with time and show up poorly in the long run as compared with methods that follow natural vegetative processes. If we work with Nature, erosion control problems are simplified and the probability of success becomes more certain than if we disregard the examples of successful natural stabilization to be found on every hillside and proceed to attack the problem from a mechanical angle.

By artificially speeding up the stabilization process, thereby creating conditions in one season which Nature could not duplicate in several years, we find that we can shorten the time required for complete control.

Much of the value of slope stabilization treatment is lost unless proper maintenance can be given during the all-important first and second years after installation, and as required thereafter. Cost of timely maintenance is not high, but neglect can bring about increased and unnecessary expenditures due to the necessity of cleaning gutters and repairing gullies which threaten the traveled way, and of frequently rebuilding portions of roadways at fill locations.

Highway construction standards now encourage the use of flatter slopes in erosion-prone soils. Flatter slopes allow the use of thicker blankets of topsoil which can support a more vigorous growth of vegetation without tending to slump when saturated. Control problems are eased considerably, and the need for maintenance reduced.

As new successful erosion control projects are completed and the consequent reduction in maintenance cost for repair of erosion-caused damage becomes more evident, highway employees are taking a greater interest in the program. Highway engineers have been particularly cooperative in developing methods which would be both practical and effective, and highway maintenance forces have become more conscious of the value of prevention. There is still a decided need for continued educational work, however, especially in

Nature's way. A completely stabilized slope

regard to effective methods for repair of old eroded slopes, and it is believed that eventually this work will be done as a matter of course.

Experimental work will be continued. Even though it is felt that considerable progress has been made, too many questions remain unanswered and too many partial failures result from high-intensity rains to allow us to believe that the most effective methods have yet been developed.

APPENDIX

EXCERPTS FROM CALIFORNIA DIVISION OF HIGHWAYS STANDARD SPECIFICATIONS, 1949

SECTION 13
EROSION CONTROL

(a) **Description.**—Erosion control shall consist of furnishing and spreading top soil on prepared roadway cut and embankment slopes and other areas shown on the plans or designated by the Engineer; preparing the spread top soil for planting; furnishing and sowing seed of the formula and variety specified in the special provisions; and furnishing and incorporating a straw mulch cover material with the planted soil; all as shown on the plans and directed by the Engineer, and in accordance with these specifications and any requirements of the special provisions.

When specified in the special provisions or ordered by the Engineer, a fertilizer shall be incorporated with the top soil as hereinafter specified.

(b) **Top Soil.**—Top soil shall consist of a fertile, friable soil of loamy character, typical of the top soil in the locality, and shall contain a normal amount of organic matter. It shall be obtained from well drained arable land and shall be free from subsoil, refuse and other deleterious substances, and shall be reasonably free from roots, hard dirt, heavy or stiff clay, stones larger than one inch (1″) in size, coarse sand, noxious weeds, noxious weed seeds, sticks, brush, and other litter. Top soil shall be free from toxic amounts of either acid or alkaline elements and shall be capable of sustaining healthy plant life.

All large lumps or clods in the top soil shall be thoroughly broken up before being spread on the prepared areas.

Top soil shall be excavated to the lines and depths ordered by the Engineer, the depth of excavation to be such that the soil being excavated will be of the same composition and structure throughout.

Top soil shall be obtained by removing existing top soil from within excavation and embankment areas, or shall be imported by the Contractor, if an item of imported top soil is included in the special provisions and contract for the work.

Imported top soil shall be defined as material obtained from sources, the selection of which, unless otherwise specified in the special provisions, is optional with the Contractor regardless of whether or not the State has made arrangements for the use of such sources. Unless otherwise provided in the special provisions, the Contractor shall make his own arrangements for obtaining imported top soil and he shall pay all costs involved.

Top soil obtained from within excavation and embankment areas shall be removed only from the locations designated by the Engineer. The top soil shall be handled directly from excavation to the location where it is to be used, as specified under article (e) below except when stockpiling is ordered in writing by the Engineer, as provided in Section 12, Chapter II, article (f), of these specifications. When ordered in writing by the Engineer, top soil obtained from within excavation and embankment areas, shall be stockpiled at locations designated by the Engineer and later placed as herein specified.

The excavation and removal of top soil from within excavation and embankment areas, and the excavation and removal of imported top soil, shall at all times be under the direction of the Engineer and only material designated by the Engineer as suitable for use as top soil shall be removed and placed as top soil cover. Top soil removed from excavation and embankment areas, and which, in the opinion of the Engineer, is not suitable for use as top soil cover, shall be disposed of as other roadway excavation, as directed by the Engineer.

In advance of excavating imported top soil, the Contractor shall notify the Engineer of the location where he proposes to obtain the material, and top soil for use on the roadway shall not be removed until the proposed material site has been approved by the Engineer. Each load of imported top soil shall be approved by the Engineer before being hauled to the roadway and unapproved loads of imported top soil will not be paid for.

(c) **Preparation to Receive Top Soil.**—Roadway slopes upon which top soil is to be spread, but only those slopes specifically designated by the Engineer, shall be roughened and loosened parallel to the roadway, by cultivating in such a manner that the top soil when spread, will be retained upon the slopes. Cultivation of slopes shall be performed as the excavation proceeds and delay in such work will not be permitted. No preparation of embankment slopes is to be performed.

(e) **Spreading Top Soil.**—Top soil to be spread upon roadway cut slopes in connection with erosion control shall be deposited in uniform windrows along the tops of the slopes in the quantity ordered by the Engineer and in such manner that it may be uniformly spread upon the slopes. Upon completion of roadway excavation and before or after finishing of gutters, as ordered by the Engineer, the top soil shall be uniformly spread over the slopes to a depth of approximately two inches (2″), the exact depth to be ordered by the Engineer.

Top soil shall be spread upon embankment slopes at the locations and to the depths ordered by the Engineer.

Top soil shall be spread upon areas to be landscaped to a uniform depth of six inches (6″), unless otherwise specified in the special provisions or ordered by the Engineer.

The type of equipment used to spread top soil and the method of spreading shall be subject to the approval of the Engineer.

(f) **Fertilizer.**—When called for in the special provisions or ordered by the Engineer, a fertilizer conforming to the specified requirements shall be furnished and incorporated with the top soil.

(g) **Seeding and Straw Cover Material.**—Immediately after top soil has been spread upon roadway slopes, such areas together with other areas designated by the Engineer shall be planted with seed, the variety of seed and the rate of sowing to be specified in the special provisions.

Immediately after seeding as above specified, the seeded areas shall be uniformly covered with rice, barley, wheat or oat straw in accordance with the following provisions:

Excavation slopes and other areas as designated by the Engineer shall be uniformly covered with straw spread at the approximate rate of four (4) tons per acre. The straw shall be incorporated with the soil by shoving it into the loose surface by means of a tamping roller or by other methods approved by the Engineer.

When specified or ordered by the Engineer and immediately after seeding, embankment slopes shall be covered with straw spread at the total rate of approximately six (6) tons per acre and rolled with a tamping roller.

If ordered by the Engineer, the embankment slopes shall be given a preliminary rolling before straw is applied in order to stabilize the loose soil sufficiently to minimize downward movement of the straw during subsequent rolling operations and the cost thereof will be paid for as extra work, as provided in Section 4, article (d), of these specifications.

The straw shall be spread upon the embankment slopes in two spreadings of approximately equal amounts, the exact amount per spreading to be determined by the Engineer, and after each spreading, the straw shall be rolled with a tamping roller a total of six (6) times. At least three (3) round trips of the roller will be required after each spread of straw.

Unless otherwise permitted by the Engineer, embankment slopes shall be seeded and covered with straw, in conformance with the above provisions, immediately following completion of each twenty foot (20′) height of embankment, or if the total height of embankment is less than twenty feet (20′), as soon as the embankment has been completed.

When the contract does not include a pay item for seed or straw cover material, the furnishing and planting of seed or the furnishing and incorporating of straw cover material is not to be performed.

(h) **Measurement and Payment.**—For payment purposes top soil obtained from within excavation and embankment areas shall be considered as selected roadway excavation, and shall be excavated, measured and paid for as herein specified and as provided under Section 12, Chapter II, articles (f), (g) and (h), of these specifications; and the price paid per cubic yard for roadway excavation shall include full compensation for furnishing all labor, materials, tools and equipment, and doing all the work involved in excavating, loading, hauling, and spreading the top soil over the prepared areas as herein specified, except overhaul which will be paid for as provided in Section 12, Chapter IX, of these specifications.

Quantities of imported top soil to be paid for will be determined as provided in Section 9, article (a), of these specifications, the unit of measurement to be determined by the Engineer and set forth in the Notice to Contractors, Proposal and Contract; and the price paid per ton or per cubic yard for imported top soil shall include full compensation for furnishing all labor, materials, tools and equipment, and doing all the work involved in clearing the material site, if necessary, and furnishing, excavating, loading, hauling, and spreading the imported top soil as herein specified.

Full compensation for placing top soil in windrows along the tops of cut slopes and later removing and spreading the material over the prepared slopes, as hereinbefore

specified, shall be considered as included in the contract price paid per cubic yard for roadway excavation or the contract price paid for imported top soil, as the case may be, and the placing of such material in windrows will not be considered as stockpiling within the meaning of Section 12, Chapter II, article (f), of these specifications.

The preparation of roadway slopes to receive top soil in connection with slope erosion work will be paid for at the contract price per square yard (slope measurement), for preparing slopes (erosion control), which price shall include full compensation for furnishing all labor, materials, tools and equipment, and doing all the work involved in preparing slopes for erosion control work as herein specified.

The price paid per ton for straw cover material (erosion control) shall include full compensation for furnishing all labor, materials, tools and equipment, and doing all the work involved in furnishing and incorporating straw on the planted areas as herein specified, except as otherwise provided under article (g) above.

The price paid per pound for seed (erosion control) shall include full compensation for furnishing all labor, materials, tools and equipment, and doing all the work involved in furnishing and sowing the seed as herein specified.

Furnishing and incorporating fertilizer with top soil will be paid for as provided in the special provisions, except that when the contract does not contain a pay item for such work, and such work is ordered by the Engineer, furnishing and incorporating fertilizer with top soil will be paid for as extra work, as provided in Section 4, article (d), of these specifications.

EXCERPTS FROM SPECIAL PROVISIONS FOR ROADWAY CONSTRUCTION CONTRACT, CITY CREEK ROAD, SAN BERNARDINO MOUNTAINS

(h) **Slope Erosion Protection.**—Furnishing and placing seed and straw and compacting slopes shall conform to applicable portions of Section 13 of the Standard Specifications and these special provisions.

Slopes shall be seeded evenly at the rate of two hundred (200) pounds per acre with a mixture consisting of fifty percent (50%) winter wheat, forty-five percent (45%) rye grain, and three percent (3%) alfalfa seed, and two percent (2%) mustard seed, by weight. No seeding shall be done during windy weather nor when the ground is frozen or in an otherwise unsuitable condition.

———

Immediately after seeding, the seeded areas shall be uniformly covered with rice, barley, wheat or oat straw spread at the approximate rate of three (3) tons per acre, and the straw shall then be incorporated with the soil by rolling with a tamping roller until each section of the slope has been rolled a total of six (6) times. Three round trips of the roller will be required. If ordered by the Engineer, the slope shall be given a preliminary rolling before straw is applied in order to stabilize the loose soil sufficiently to minimize downward movement of the straw during the rolling operation.

Unless otherwise permitted by the Engineer, embankment slopes shall be seeded and covered with straw, in conformance with the above provisions, to each 10-foot height of embankment as soon as that portion of the embankment has been completed.

If ordered by the Engineer, the Contractor shall apply water to embankment slopes before compaction. Water for such use shall be applied in a fine spray to avoid slope erosion, and will be paid for at the price per thousand gallons for applying water (slope erosion protection and preparing subgrade).

An additional application of straw shall then be spread at the approximate rate of three (3) tons per acre, and the straw incorporated with the soil by rolling as specified above.

The tamping roller shall conform to the provisions of Section 12, article (u), of the Standard Specifications, except that the studs and tamping feet shall be so designed that they will not withdraw the straw or wire mats from the fill. * * *

The State will perform additional planting by State forces after the Contractor has completed the slope erosion protection herein specified. The Contractor shall permit access to embankment slopes by State forces and their equipment and shall permit their use of his construction roads for additional planting work insofar as such work does not

interfere with his operations. Such additional work by State forces shall not be construed as acceptance of any part of the Contractor's work or relieving the Contractor of maintenance of embankment slopes until the contract is accepted.

---

(1) **Wire Mats.**—During the construction of embankments, wired mats shall be placed in embankment slopes as shown on the plans and as directed by the Engineer.

Wire mats on a portion of the project shall consist of two (2) courses of camouflage wire fifty-eight inches (58″) wide, doubled and placed between two (2) courses of fifty-eight inch (58″) wide wire fabric or fencing. Camouflage wire will be furnished by the State as hereinbefore provided.

Wire mats on a portion of the project shall consists of three (3) layers of sixty inch (60″) wide poultry netting between two (2) courses of fifty-eight inch (58″) wide wire fabric or fencing.

Wire fabric or fencing for use in wire mats shall be at least fifty-eight inches (58″) wide and shall consist of longitudinal and transverse strands either welded or twisted together at the intersections. The longitudinal strands shall be parallel to the sides of the fabric and spaced not more than two inches (2″) apart. Transverse wires may be at right angles or diagonal to the direction of the longitudinal wires and spaced such that the area of openings is not more than four (4) square inches. Longitudinal and transverse wire shall not be smaller than 14 gauge and shall be galvanized after fabrication.

Poultry netting shall be one-inch hexagonal mesh, twenty gauge wire, galvanized after weaving.

When the embankment has been constructed to the required elevations for wire mats, the surface to receive the mats shall be made smooth and parallel with the grade of the highway.

Mats consisting of camouflage wire and of poultry netting shall be placed by laying the bottom course of fencing, the two double courses of camouflage wire or four (4) courses of poultry netting and top course of fencing, on the prepared grade in the order named; the position of the mats being such that the embankment cover at the outer edge will be six inches (6″) normal to the fill slope before compaction. Bottom and top courses of fabric or fencing shall be lapped a minimum of ten feet (10′) at splices on each layer where the ends of rolls occur and tied with fourteen (14) gauge galvanized iron tie wire the full width and length of the lap at intervals of not more than fifteen inches (15″) across each end and five feet (5′) across the width. The camouflage wire or four layers of poultry netting and upper and lower courses of wire fabric or fencing shall be tied together at each longitudinal edge and center with fourteen (14) gauge galvanized tie wire at intervals of not to exceed five feet (5′) before placing embankment cover. Center ties shall be staggered equi-distant from the edge ties.

Mats shall extend continuously for the full length of the fill and a distance of five feet beyond the intersection of the fill and natural ground slopes at each end and shall be warped at the ends so that the portion extending outside the fill will be on the ground surface. The mats shall be held securely in place by some means satisfactory to the Engineer until covered by embankment material. The end portion of mats extending outside the fill slopes shall be staked and tied securely in place by use of metal stakes and wire satisfactory to the Engineer.

The prices paid per lineal foot for wire mats (poultry netting, erosion protection) and wire mats (camouflage wire, erosion protection) measured along the mats parallel to the center line of the highway, shall include full compensation for preparing the surface, furnishing and placing wire fabric or fencing, hauling and placing camouflage wire, furnishing and placing poultry netting, furnishing tie wire and tieing mats, furnishing and driving stakes to hold mats in position, and all incidental labor and materials required to construct the wire mats as herein specified; except for camouflage wire which will be furnished free of cost to the Contractor.

No additional compensation will be allowed for placing and compacting embankment material on wire mats.

EXCERPT FROM SPECIAL PROVISIONS FOR ROADWAY CONSTRUCTION CONTRACT NEAR SANTA CRUZ

(f) **Earthwork.**—Topsoil to a depth of two-tenths foot (0.2′), or to a depth directed by the Engineer, shall be removed from the area between slope lines of both the excavation and embankment areas and stockpiled in windrows outside the slope lines. Excavating and windrowing topsoil will be measured and paid for as roadway excavation as provided in Section 12, articles (i) and (j), of the Standard Specifications.

* * * * * * *

(h) **Slope Erosion Protection.**—At locations directed by the Engineer, excavation and embankment slopes and areas outside the slope stakes shall be protected from erosion in conformance with Section 13 of the Standard Specifications except as herein provided.

Topsoil obtained as provided under "Earthwork" of these special provisions, shall be spread over the slopes. The resulting cover shall be neat appearing and vary from one inch (1″) to three inches (3″) in depth depending on the amount and character of topsoil available.

After the topsoil is spread over the slopes, the following operations shall immediately follow in sequence with care being taken to prevent pushing the loose topping down the slopes.

At 6-9-6 or 6-10-4 commercial fertilizer shall be furnished and spread over the topsoil at the rate of forty (40) pounds per one thousand (1000) square feet.

The fertilized slopes shall be planted with western rye-grass seed furnished and sown at the rate of one (1) pound per two hundred (200) square feet.

The planted areas where directed by the Engineer, shall be uniformly covered with straw as provided in Section 13, article (g), of the Standard Specifications. Sheepsfoot tampers shall be used to incorporate the straw with the soil.

* * * * * * *

Payment for the various items of slope erosion protection shall be as specified in Section 13, article (h), of the Standard Specifications. Payment for fertilizer shall be as set forth below.

The price paid per ton for fertilizer (slope erosion protection), shall include full compensation for furnishing all labor, materials, tools and equipment and doing all work involved in furnishing and spreading fertilizer on slopes as herein specified.

(i) **Preparing Curbed Areas (Ground Cover Planting.)**—Curbed island areas shall be prepared for ground cover planting. The areas shall be scarified and thoroughly cultivated to a depth of twenty-four inches (24″) below the line of top of curbs. Scarifying shall not be performed within an area one foot (1′) from the back of the proposed curbs. Excess material shall be removed and low places filled in until the top of cultivation is uniformly seven inches (7″) below the line of top of curbs.

After the proper porosity and repose of the subsoil is obtained, topsoil from the sources provided under earthwork of these special provisions shall be placed between curbs. The surface of the topsoil shall be leveled off one inch (1″) below the line of top of curbs.

During operations in preparing curbed areas, the curb shall be fully protected from injury by the Contractor at his own expense. Any discoloration caused by spilling soil shall be removed by the Contractor at his own expense.

Preparing curbed areas (ground cover planting) will be paid for by the square yard, which price shall include full compensation for furnishing all labor, material, tools and equipment and performing all the work involved as herein specified except loading, hauling and depositing topsoil.

Loading, transporting and depositing topsoil in the curbed areas will be paid for at the price for roadway excavation measured in the truck at the point of delivery as provided in Section 9, article (a), of the Standard Specifications. Overhaul will be paid for as provided in these special provisions.

(j) **Ground Cover Planting.**—Upon completion of slope erosion protection and placing topsoil in curbed areas as herein specified, Mesembryanthemum edule (Ice Plant) cuttings shall be furnished and planted in conformance with the following provisions or as directed by the Engineer.

In central curbed division strips, plants shall be placed at two foot (2′) centers in neat rows with the plants in adjacent rows staggered. The rows shall be parallel with the line of travel and in general two feet (2′) apart. All curbed strips shall have a minimum of two (2) rows.

On embankment slopes outside and below the berm or shoulder and above excavation slopes on the topsoil berm, plants shall be

placed at two foot (2′) centers in two longitudinal rows two feet (2′) apart measured horizontally with the plants in adjacent rows staggered.

Ice Plant cuttings shall not be less than ten inches (10″) long and shall be tip cuttings taken from healthy, vigorous, strong growing vines. Mature or brown colored stem growths or cuttings which have been trimmed or rooted before planting will not be accepted. Cuttings shall not be allowed to dry or wither before planting.

Cuttings shall be planted in moist, loosely cultivated soil, and shall be so placed that not less than two (2) nodes, are covered with soil and the basal end shall be not less than four inches below the surface of the soil. After planting each cutting shall be immediately watered if ordered by the Engineer. Planting shall be completed at least thirty (30) calendar days prior to the date of acceptance of the contract.

The Contractor shall maintain at his own expense, and in a satisfactory and workmanlike manner, the areas with ground cover planting until the date of acceptance of the conract. He shall replace at his own expense any and all plants which fail to grow or which are so injured or damaged as to render them unsuitable for the purpose intended. The necessary replacements shall be made immediately following any indications of withering or growth failure. Any replacements which fail to grow during the maintenance period shall also be replaced at the Contractor's expense.

The State reserves the right to eliminate any portion of, or the entire item of planting Ice Plant cuttings, if, in the opinion of the Engineer, the season of the year and soil moisture conditions at the time ice plant cuttings are to be planted are unfavorable for the establishment of the plants. No additional compensation will be allowed by reason of such elimination.

Quantities of cuttings to be paid for will be determined by actual count upon completion of the contract.

The unit price paid for Mesembryanthemum edule cuttings (Ice Plant) shall include full compensation for furnishing all labor, materials, tools and equipment and for doing all work necessary to plant the ground cover as herein specified. Furnishing and applying water will be paid for as provided elsewhere in these special provisions.

EXCERPT FROM SPECIAL PROVISIONS FOR LANDSCAPE CONTRACT NEAR HOLLYWOOD

(c) **Plants.**—All plants shall be healthy, shapely, and well rooted, and roots shall show no evidence of having been restricted, deformed or root bound at any time. They shall be well grown, free from insect pests, and shall have been grown in nurseries which have been inspected by the State Department of Agriculture and have complied with the regulations thereof, except when the special provisions provide that the plants may be obtained from present growth at or near the site of the work.

All plants shall be first-class representatives of their normal species or variety unless otherwise specified. They shall have well developed branch systems with vigorous and fibrous root systems. Plants shall be free from disfiguring knots and sun scald injuries, abrasions of the bark, or other objectionable disfigurements. Plants not conforming to the requirements herein specified shall be considered as defective, and such plants, whether in place or not, will be marked as rejected, and shall be immediately removed from the site of the work and replaced with suitable plants.

All plants shall be of the size, age and condition as specified herein or as shown on the plans or as specified by the Engineer.

(d) **Inspection of Plants.**—All plants shall comply with Federal and State Laws requiring inspection for plant diseases and infestations.

Any inspection certificates required by law shall accompany each shipment, invoice or order for stock and when such plants arrive at the site of the work, the certificate of inspection shall be filed with the Engineer.

(e) **Preparation for Shipment.**—All plant material shall be dug with care and precautions shall be taken to avoid injury to or removal of fibrous roots. Each plant shall be handled and packed in the approved manner for that species or variety and all precautions shall be taken necessary to insure the arrival of the plant at the site of the work in proper condition for successful growth.

(f) **Shipment.**—Plants shipped by truck shall be packed in such a manner as to insure adequate protection against windburn and against climatic, seasonal or other injuries during transit. All deciduous trees and shrubs

shall be placed in separate bundles and the roots shall be protected with wet straw, moss or other suitable materials.

(g) **Tagging.**—All plants shall be true to name and shall be tagged with the name in accordance with the standards of practice recommended by the American Association of Nurserymen.

(h) **Planting Materials.**—Commercial fertilizer shall be 6-9-6 or 6-10-4 unless otherwise specified.

Manure shall be from cattle corrals, shall be free of noxious weed seed or other objectionable material, and shall be satisfactory to the Engineer.

Tree stakes shall be of such dimensions as specified by the Engineer and shall be placed only at such trees as designated by the Engineer. The furnishing and installation of tree stakes will be paid for as extra work as provided in Section 4, article (d), of the Standard Specifications.

Sprinklers will be furnished by the State.

(i) **Plant Location.**—The Engineer will designate by means of suitable stakes or by directing the placement of the plants the exact locations where the various varieties of plants are to be planted.

(j) **Preparation of Planting Areas.**—Planting preparation for ground cover areas shall conform to the following order:

1. Checking of watering system.
2. Thorough moistening of soil.
3. Application of commercial fertilizer.
4. Cultivation of ground.
5. Planting.

Preparation for planting of ground cover areas shall conform to the following specifications:

Checking of Watering System.—Before the soil is cultivated, the watering system shall be checked thoroughly for any necessary adjustment which is needed to obtain uniform coverage. All pipe connections, turning unions and valve packing glands shall be checked for leakage and tightened if necessary. Nozzles and sprinkler heads shall be checked for proper operation, and nozzles replaced if found to be defective. The cost of the above checking and the cost of making any change or adjustment in the watering system will be paid for as extra work as provided in Section 4, article (d), of the Standard Specifications.

Thorough Moistening of Soil.—Following checking of the watering system, the soil shall be thoroughly moistened by means of the watering system preparatory to cultivation. Extreme care shall be taken that the water is not allowed to run in any one area to the point where runoff or saturation which could cause erosion might occur.

The cost of moistening the soil prior to cultivation will be considered as included in the price paid per square yard for cultivating planting areas.

Water will be furnished by the State.

Application of Commercial Fertilizer.—Commercial fertilizer shall be applied uniformly to areas in which ground cover plants are to be planted at the rate of 30 pounds per thousand square feet. The first application shall be made before cultivation. Further applications shall be made if and when directed by the Engineer, and will be paid for at the unit price for commercial fertilizer in place.

Application of commercial fertilizer will be paid for by the ton, which price shall include full compensation for furnishing and placing the commercial fertilizer.

Cultivation of Ground.—After commercial fertilizer has been applied and the soil has dried to the point where it can be properly cultivated, the soil shall be thoroughly cultivated by a method satisfactory to the Engineer, until the area is in a moist, loose, fine-textured condition to a depth of not less than 6 inches.

The areas shall be finished off to present a neat and uniform appearance satisfactory to the Engineer before any planting is done, and all weeds and grass shall be destroyed. Bermuda grass shall be completely removed. Topsoil in curbed areas shall be graded uniformly to a point one inch below the top of the curb.

Areas which are not to be planted to ground cover plants need not be cultivated, but shall be finished off to present a neat and uniform appearance free of weeds, grass or other objectionable material after tree and shrub planting is completed.

Cultivating will be paid for at the contract price per square yard for cultivating planting areas, which price shall include full compensation for furnishing all labor, tools and equipment and doing all work involved in cultivating the planting area as above specified.

(k) **Planting.**—Planting holes for trees, shrubs and vines shall be dug at the exact staked locations and shall be of sufficient width and depth to receive the roots of the plants without doubling back or crowding. Holes for plants shall be of sufficient width and depth to allow for not less than 6 inches of topsoil to be flushed in and around the root area or ball of earth surrounding the roots.

Planting holes shall be backfilled with friable topsoil and plants set in the holes to such depth that upon settlement they will be at their natural growing depth. Soil shall not be mechanically tamped or compacted around the roots or ball of the plant during or after the planting operation. Topsoil for backfilling may be obtained from topsoil previously placed on the project. The soil resulting from the excavation of tree, shrub and vine holes shall be utilized in forming a basin not less than three feet (3′) in diameter, or of such shape and dimensions as the Engineer directs, around each tree, shrub or vine. The initial watering shall be done with a pipe jet which shall be inserted alongside the plant to the depth of the hole, and the soil saturated from the bottom up.

After the topsoil has been flushed in and around the roots or ball of the plant, and the basin as hereinbefore prescribed is constructed, manure at the rate of one (1) cubic foot per plant shall be spread evenly around each plant, and the basin shall then be filled with water.

Trees, shrubs and vines will be paid for on a unit price basis, which prices shall include full compensation for furnishing and planting the various varieties of plants complete in place, including manure mulch.

Lantana sellowiana and Hedera helix plants in bottomless wooden plant bands, not less than 2″ x 2″ x 3″, shall be planted without removing plant bands. If furnished in pots (not less than 2½″) or flats, they shall be sufficiently established to retain a ball of earth around the roots during planting operations. Growth above soil surface of Lantana plants shall be not less than two inches (2″) long, and growth above soil surface of Hedera plants shall be not less than four inches (4″) long.

Holes in which plants in plant bands are to be planted shall be formed with flat bottoms, and shall be of such depth that the surface of the soil in the plant band is level with the surrounding soil after planting and watering has been completed. Soil used for backfilling planting holes must be moist, fine textured and friable. Backfilling of planting holes with clods or lumpy soil and mechanical compaction of soil around the plant band will not be permitted.

Lantana and English Ivy shall be planted in moist, friable soil, eighteen inches (18″) apart, except where otherwise noted on the plans, in locations as shown on the plans and as specified by the Engineer. Lantana and English Ivy plants shall be individually watered immediately after planting by using a slow running hose or other satisfactory means. The sprinkler system shall not be used for watering English Ivy and Lantana until specified by the Engineer. Individual watering as above specified will be only required immediately after planting. All ground cover plants shall be kept properly watered until acceptance of the contract. Construction of basins and application of manure mulch will not be required for ground cover plants.

No ground cover planting will be permitted in soil which is too wet or too dry. The soil in which ground cover plants are planted must be moist, fine textured and friable in order that the fine soil particles may completely surround the roots. Soil shall be placed firmly around the roots of all plants, and planting in lumpy soil will not be permitted.

Plants shall not be allowed to dry out before or while being planted. The root area shall be kept moist by means of wet sawdust, peat moss or burlap at all times during planting operations, and shall not be exposed to the air except while actually being placed in the ground. Wilted plants whether in place or not, will not be accepted.

Workmen shall not be allowed to walk on the planting areas unnecessarily during or after preparation and planting operations. Planting areas that have been compacted for any reason shall be recultivated at the Contractor's expense.

Ground cover plants will be paid for on a unit price basis which shall include full compensation for furnishing and planting the various varieties of plants complete in place.

(n) **Watering.**—All plants shall be kept properly watered until acceptance of the contract.

No watering shall be done on planted areas until actual investigation of the soil indicates that water is needed.

Water shall not be allowed to run so long in any section that runoff or saturation which could cause slippage or undue compaction might occur.

Any loss of topsoil or plants due to runoff erosion or slippage shall be repaired or replaced at the Contractor's expense.

Water will be furnished by the State.

INDEX

	Page
Appendix—Specifications	63–70
Brush Layers	17, 18, 44–48
Brush Mats	17, 18, 44–48
Burning, Roadside	33–35
Check Dams	22, 23
Climate	1
Conclusions	59, 60
Cut Slopes—Problem on	10–12
Cut Slopes—Treatment of	13–14, 51
Cut Slopes—Maintenance of Stabilized	53–55
Ditches	20–22
Early Control Problems	6– 9
Fill Slopes—Problem on	14–16
Fill Slopes—Treatment of	16–18, 44–48
Fill Slopes—Maintenance of Stabilized	53–55
Fire Hazard	33–35
Grasses	26–28
Ground Cover Planting	28, 29; 67–70
Maintenance of Stabilized Slopes	36–38
Natural Slopes	5, 6
Plant Band Planting	30, 31; 70
Plant List—Plants Planted in Bands	32
Plant List—Ground Cover Plants	29
Rainfall Data	1, 2
Repair of Failures—Recently Stabilized Slopes	53–55
Repair of Failures—Old Eroded Slopes	55–58
Rock Method for Fill Slope Stabilization	48
Sand Stabilization	23–25
Seeding	26–29
Sheepsfoot Methods	51–53
Shoulders—Treatment of	18-19
Slope Stabilization Detail Sheet	41
Soil Types	4
Specifications—Erosion Control, General	63–65
Specifications—Erosion Control, Special Provisions	65, 66
Specifications—Erosion Control, Ground Cover Planting	67, 68
Specifications—Tree, Shrub and Ground Cover Planting	68–70
Straw Mulches—Use of in Slope Stabilization	50, 51
Trees and Shrubs—Planting	30–32, 68–70
Type A Stabilization	39–41
Type B Stabilization	40, 41
Type C Stabilization	41–43
Wattles	48, 49
Wind Erosion	23–25
Wire Mats	46–48; 65, 66

o

32765 9-50 5M