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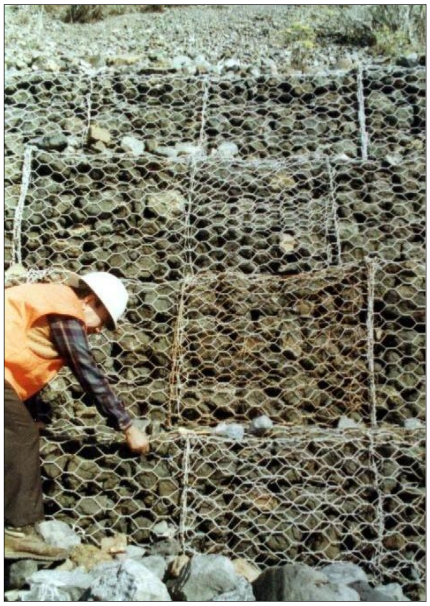
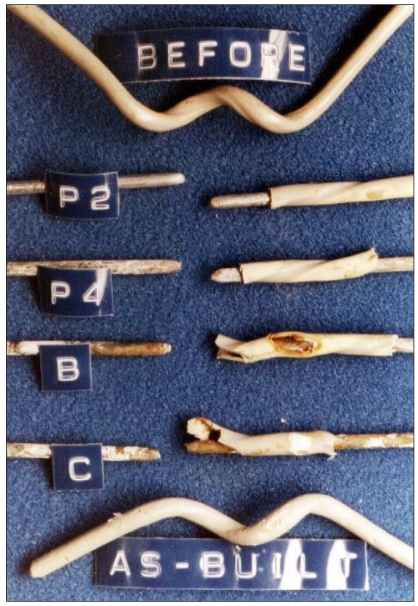
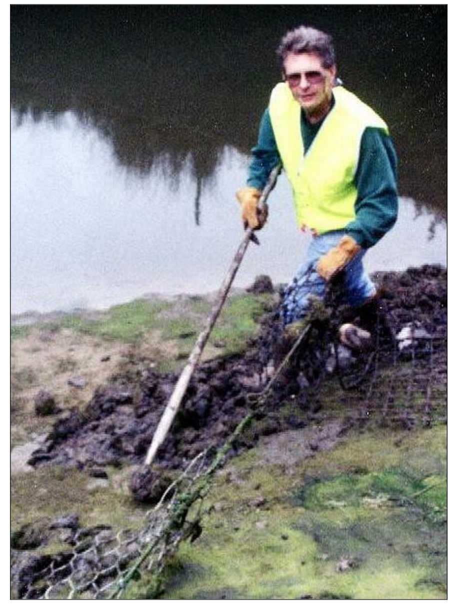






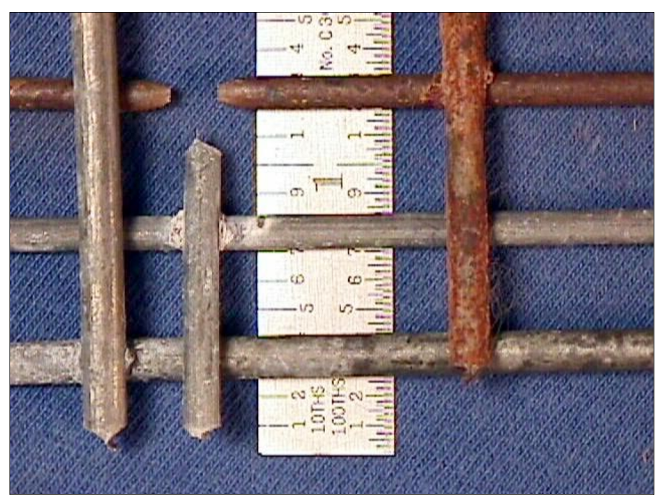
GABION MESH CORROSION

Field Study of Test Panels and Full-scale Facilities

by James A. Racin, P.E. and Thomas P. Hoover, P.E.

Report No. FHWA-CA-TL-99-23 Study No. F93TL02 S

November 2001 2nd edition
(minor revisions to 1st edition of May 2001)



Prepared in Cooperation with the US Department of Transportation Federal Highway Administration

STATE of CALIFORNIA
DEPARTMENT of TRANSPORTATION
DIVISION of NEW TECHNOLOGY and RESEARCH

GABION MESH CORROSION
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Final Report No. FHWA-CA-TL-99-23
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November 2001 second edition

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16. ABSTRACT

Caltrans did a long-term field study of corrosion and other damaging effects on wires of gabion mesh at 14 sites in California. At most sites there was a full-scale gabion facility: channel lining, energy dissipater, retaining wall, or slope protection. Two styles of mesh were studied: twisted hexagonal and welded square-grid. The wires had corrosion-protection coatings of either zinc, zinc-and-polyvinyl chloride (PVC-coated), or aluminum. Test panels from 8 products were installed at 5 of 6 sites with full-scale facilities. At a 6th tidally influenced site there were only test panels. Additional sites were investigated where there are full-scale gabion facilities, and only 1 of those sites had test panels of 2 products. When feasible, wire samples were collected from test panels and from full-scale facilities. Samples were tested to failure in tension. Wire strength, expressed as ultimate tensile force, was the fixed variable of the experiment. The null hypothesis was : Is there a difference between mean ultimate tensile forces BEFORE and AFTER exposure at field sites ? BEFORE values were determined in a prior laboratory study of accelerated corrosion. The random variable was location. More precisely, at field sites the local exposures to soil, air, water, and/or sunlight influenced wire corrosion and other damaging effects, and hence gabion performance and service-life. As contrasted to air exposure, some soil and/or water exposures resulted in large measurable losses of wire strength and/or gabion failures. Site-specific soil and water factors are presented to reveal their possible influence on tensile test results, performance, and service-life of gabions. Test panels did not always indicate what happened to a gabion facility, because we often placed test panels in easily accessible areas, which may have received less severe exposure than other parts of the structure. Where severe exposures are expected, alternative designs or materials other than gabions should be considered. From this and prior studies, standard plans and material specifications were developed. They are available on a Caltrans Internet site, and they are included in Appendix A as Standard Plans D100A and D100B and material specifications for zinc-coated and PVC-coated gabions.

Note on 2nd edition. Owners of the 1st edition (May 2001) should replace pages 16, 56, and 107 (Acrobat pages 28, 68, and 119). A few other pages have minor corrections. Conclusions and recommendations are identical in both editions. For general guidance see CONCLUSIONS (last paragraph of page 99, all of page 100), RECOMMENDATIONS (pages 101 through 105), and APPENDIX A (pages 110 and 126). All photos were darkened to improve the images. JAR

17. KEY WORDS

gabion, wire, mesh, corrosion, polyvinyl chloride, PVC, zinc, galvanized, aluminum, strength, ultimate tensile force, standard plans, specifications, soil, water, air, exposure, performance, service-life, retaining wall, channel lining, slope protection, energy dissipater

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UNITS and CONVERSION FACTORS

In the gabion mesh corrosion study, we measured and reported most wire, soil, water, and air properties in US customary units. For wire properties (diameters, zinc coating thickness, etc.), we used ASTM A 641, the 1989 Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire. When ASTM metricated A 641, zinc coating thicknesses were defined for ranges of wire diameters, so conversions may not be exact. The Caltrans gabion specifications in Appendix A are in SI units, and they reflect the ASTM A 641/A 641M-97 standard. The following tables show wire gages that we investigated and various units that we used with their SI conversion factors.

US unit, 1 mil = 0.001 inch

USA wire gage	diameter, mils	minimum allowable average gabion wire diameter with Class 3 zinc-coating, mils
9	148	144
10	135	131
10.5	130	126
11	120	116
12	106	101
13.5	86	82 (standard tie wire)

US customary unit (abbreviation)	multiply by	to get SI, metric unit
mils	0.0254	millimeters (mm)
inches (in or “)	25.4	millimeters (mm)
feet (ft or ‘)	0.3048	meters (m)
cubic feet / second (cfs)	0.0283	cubic meters / second (m^3/s)
feet / second (fps)	0.3048	meters / second (m/s)
pounds force (lb)	4.45	Newtons (N)
pounds force (lb)	0.00445	kiloNewtons (kN)
kilopounds / square inch (ksi)	6.8948	megaPascals (MPa), or (N/mm^2)
pounds mass (lb)	0.4536	kilograms (kg)
ounces / square foot (oz / ft^2)	305.17	grams / square meter (g/m^2)
pounds / cubic foot (lb / ft^3)	16.0185	kg / m^3
plane angle (degrees)	0.0175	radians (rad)
degrees Fahrenheit (F)	(F-32) / 1.8	degrees Celsius (C)
micro-mhos	1	micro-siemans
parts per million (ppm)	1	milligrams per liter (mg/L)

The SI unit, ohm**.**centimeters (ohm-cm), is for minimum resistivity of soil in corrosion studies.

NOTICE

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The findings do not necessarily reflect the official views or policies of the State of California, Department of Transportation (Caltrans) or the Federal Highway Administration (FHWA).

This report does not constitute a standard, specification, or regulation, and this report is not an endorsement of gabion products. Ongoing source and contract compliance testing is essential for satisfactory applications of gabions. Neither the State of California nor the United States Government endorses specific products or manufacturers. Names of manufacturers, trade-marks, and names of patented devices may appear where they are considered essential in the context of the report.

Recommendations and conclusions are specific to materials of gabion products which were sampled, tested, evaluated, and reported. It was assumed that test panels were representative of normal wire production and gabion manufacturing processes. Caltrans waives responsibility of interpretations and extrapolations of conclusions and recommendations regarding gabion materials which may have been produced after 1989.

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PHOTOS grouped by SITE. Brief descriptions here, actual photo captions are very detailed.

1. INTRODUCTION

BACKGROUND

Gabions are wire mesh baskets that are joined successively and then filled with rock to form permeable structures, like channel lining or retaining walls. The mesh is low-carbon steel wire with coatings that delay or impede corrosion, thereby protecting the underlying wire, and perhaps extending the service-life of gabions. When they are used in appropriate settings, gabions can prevent channel erosion or stabilize slopes. However, based on experiences of the California Department of Transportation (Caltrans) and others, there are sites where gabions are not appropriate. To gain confidence and to develop some credibility in recommending appropriate materials and sites, Caltrans started studying gabion mesh corrosion in 1986. We placed test panels at several field sites in California, usually where gabion structures were already built. Then, we periodically inspected and documented performance and any failures of the full-scale gabion facilities. With data from test panels and with observations of full-scale facilities, we have begun to document how well gabions may perform, and how long some of them may last.

Before 1986 there was one widely recognized style of gabion mesh: twisted hexagonal, sometimes called double-twisted mesh. Then in 1986, Caltrans allowed the use of another style of mesh: welded square-grid. Based on full-scale demonstration tests, [Hoover, references 1 and 3, and Nelson, reference 2], it was determined that gabions made from either twisted hexagonal mesh or welded square-grid mesh, have comparable strength and flexibility. Wires of both mesh styles are usually zinc-coated, typically hot-dip galvanized. Additionally, both mesh styles can be coated with polyvinyl chloride (PVC). For simplicity in this report, “PVC-coated” actually means “PVC-and-zinc-coated”.

Both zinc-coated and PVC-coated gabions are susceptible to corrosion. The wire is composed of two dissimilar metals: zinc and a formulation of low carbon steel, which is mostly iron. Generally, galvanic corrosion occurs when dissimilar metals contact each other in the presence of an electrolyte. The electrolyte may consist of ions from dissolved soil particles or from dissolved atmospheric gases. The strength of an electrolyte will vary depending on atmospheric conditions and soil constituents and/or the source of water: humidity, rainfall, surface runoff, snowmelt with deicing salts, saline oceanic or tidal waters, brackish stagnant water, or groundwater. At field sites, bacterial action, methane and other gases, and other nonmetallic elements may contribute to corrosion. Metals tend to easily lose their electrons to nonmetals and nonmetallic ions, thereby corroding and forming various metallic oxides, chlorides, sulfides, and other compounds.

The Federal Highway Administration (FHWA) and Caltrans funded several gabion corrosion studies. From 1986 to 1993 Caltrans did a 7-year field study of full-scale gabion facilities and test panels along the Pacific Coast Highway in Monterey County [Hoover, reference 4] and [Racin, reference 5]. Those studies prompted a laboratory study of accelerated corrosion [Racin, reference 6], which gave field inspectors a rational basis for rejecting materials with damaged coatings. A task of the lab study was to do a corollary field study which started in 1989. The field study is the focus of this report.

Figure 1. Gabion Corrosion Field Sites in California

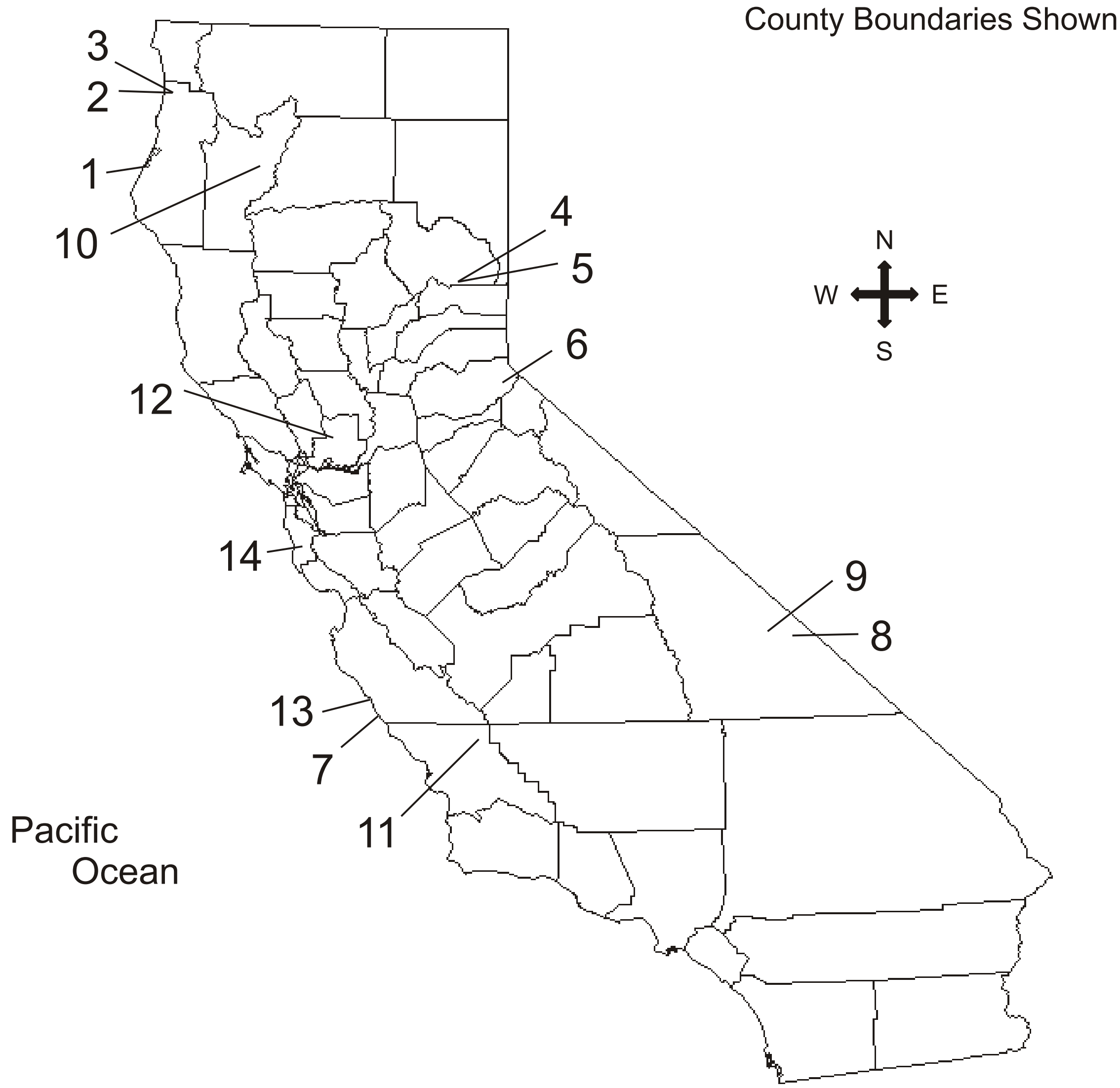


Table 1. Site Designations and Locations				
Site No.	District No.	County abbreviation	Route No.	Post Mile
1	01	Humboldt HUM	101	70
2	01	Humboldt HUM	101	125.9
3	01	Humboldt HUM	101	127
4	02	Plumas PLU	89	5.2
5	02	Plumas PLU	89	4.7
6	03	El Dorado ED	50	63.9
7	05	Monterey MON	1	7.5 - 8.1
8	09	Inyo INYO	190	122.0 -122.5
9	09	Inyo INYO	190	115.3
10	02	Trinity TRI	299	63.8
11	05	San Louis Obispo SLO	46	48.3
12	04	Solano SOL	80	R 42.8
13	05	Monterey MON	1	21
14	04	San Mateo SM	84	7.2

The field study documents corrosion of test panels and full-scale gabion facilities at 14 sites in California. See Figure 1 and Table 1. We continued observing full-scale facilities and test panels in Monterey County at site 7. We placed 63 test panels at sites 1 though 6. Sites 2 through 6 had gabion facilities. As the study progressed, we documented the performance of gabion facilities at 7 more sites without test panels. We observed gabions in continually flowing streams, in and near the ocean, in stagnant wetland waters, and in intermittent flow settings, like desert washes. All sites were next to highways.

All 14 sites provided "lessons learned" about material choice and gave us insights about site-specific design features. We observed a broad range of corrosion and other effects. At one site, zinc-coated mesh disintegrated in less than ten years, when it was buried in fine soil which was transported and deposited by saline tidal flows. At the same site, by contrast, PVC coating was discolored, the surfaces of the underlying wire had corrosion compounds, while wires had not lost their unexposed tensile strength. At many other sites, atmospheric corrosion left zinc-coated wires relatively unaffected, with the dull gray coloration of zinc carbonate [ASM International Handbook Committee, reference 7]. Gabions failed from abrasion by natural sources of sediment during storms or wave attack at several sites. While abrasion is problematic at some sites, alternative designs and/or materials other than gabions may be appropriate. At another site, gabion baskets were vandalized. We documented site-specific conditions, and we also sampled and measured some physical, chemical, and electrical properties of soil and/or water to try to explain the relatively rapid or slow corrosion or other effects. Key water properties that we measured were temperature, specific conductance, pH, and dissolved oxygen. Key soil properties that we measured were pH, minimum resistivity, and particle size distribution.

Before and during our studies, we searched the literature for information about gabion corrosion, coatings, and styles of wire mesh. No such documents were located in the library databases: TRIS, GEOREF, or COMPENDEX. Gabion manufacturers and wire fabricators had no published corrosion studies of their finished products. We received information about a US Army Corps of Engineers, Seattle District, Section 54 shoreline erosion control demonstration project on Whidbey Island in Oak Harbor, Washington [Merchant, reference 8]. Various revetment materials were built side-by-side in the intertidal zone to protect the shore [Combe, III, reference 9]. One zone of the revetment was rock-filled gabions with PVC-coated mesh, similar to the gabion materials that we studied. A severe winter storm on February 13, 1979 produced a 4-hour, 3-foot wave attack which led to failure. Here's a quote from reference 9, part of Combe's follow-up inspection in July, 1987.

> The vinyl-coated galvanized wire appears to be unsuited to a saline environment with high concentrations of sand and gravel in suspension or large amounts of debris that may tear the protective coatings and stimulate corrosion. Large debris, such as occurs at Whidbey Island, tears the baskets open like battering rams. The failure mode appears to have been the breaking of the baskets by debris and subsequent loss of stone. Further damage then results from overtopping of the damaged device resulting in the loss of fill from behind the device.

An abundance of information about corrosion is in Volume 13 of the ASM Handbook [ASM International Handbook Committee, reference 7]. There is an excellent long-term field study of wire and coatings of various fence materials at 7 sites in the United States and at Warrington in England [Occasione, Britton, and Collins, reference 10]. Their study focused on atmospheric exposure, and they have about 20 years of observations and data on corrosion rates to initial rust and the (tensile) breaking strength loss of wires. That study, our earlier gabion studies, and many discussions with the Caltrans Translab staff in the corrosion, metallurgy, and chemistry units helped to guide our efforts in studying gabion wire mesh corrosion.

OBJECTIVES

The ultimate objective was to use observations and results to describe performance and document the service-life of gabions in selected settings. By periodically inspecting gabion facilities and test panels, we were able to qualitatively judge the performance and document any loss of function. Caltrans has not formally established the number of years for gabion service-life, like they have for bridges (75-years) or culverts (50 years). Bridges are inspected periodically and rated, and then they may be repaired or replaced before major problems occur. So, in our study, loss of function is considered as an end of gabion service-life. Wire damage and gabion failure modes are further discussed in Chapter 2.

Our major data collection and analytical tasks were to obtain and compare BEFORE and AFTER values of mean ultimate tensile forces of gabion wires, that is, BEFORE and AFTER exposure to natural conditions at the field sites. Although we did not always have BEFORE data from full-scale facilities, when it was feasible, we collected a few wires, repaired the facility, then tensile-tested the wires to help explain why there may or may not have been a gabion facility failure. Collecting soil and water data also helped to explain performance and failures. We compiled a photographic log to show effects of local exposures to air, soil, water and/or sunlight. We interviewed Caltrans maintenance people and inquired if there were any accidents, fires, spills, or acts of vandalism, which would have been extraordinary effects. Where gabions may be considered, designers may be able to reasonably estimate where gabions may serve their intended functions, and where they may require ongoing maintenance or replacement, by collecting some field data and comparing local exposures to our test sites.

An implementation objective was to develop material specifications and construction details. During the research, specifications and drawings were drafted, modified, and used on several Caltrans projects. By July 1999, Standard Plans D100A (Gabion Basket Details No. 1) and D100B (Gabion Basket Details No. 2) were published in the Caltrans **Standard Plans**. Manufacturers provide specifications for their own products, however, the Caltrans specifications were written to encourage competitive pricing, by normally allowing either mesh style, twisted hexagonal or welded square-grid. One specification is for zinc-coated wire and the other is for PVC-coated wire. Separate specifications easily distinguish these distinctly different materials and their fasteners. The standard plans and specifications are in Appendix A. They are available to anyone with Internet capability. The plans and specifications in the Appendix are in metric units. In California and most of the United States, before 1995, gabions were manufactured in US units, and dimensions were in feet and cubic yards. In this report you will see mostly US units, because we started this project in US units, and our prior work was done in US units.

OVERVIEW of EXPERIMENT

In many corrosion studies, the amount of protective coating (mass or thickness) that is lost, is measured and plotted as a function of time. We wanted to obtain information about the effects of gabion mesh corrosion, which could be related directly to the performance and service-life of full-scale gabion facilities. As long as gabion baskets retain their rock-fill, they are likely to continue to perform their intended functions. Therefore we selected **ultimate tensile force** of individual wires as the **fixed variable** of the experiment. We obtained random samples of gabion materials from four gabion manufacturers. Samples represented products which were typical of wire fabricating and gabion manufacturing processes, which were used in the mid 1980's and early 1990's. Coatings, wire gages, and gabion mesh styles that we tested are summarized in Table 2. We cut whole gabion panels in half to yield test panels that measured 18-inches by 36-inches. We then selected and broke corrosion-free wires to establish the mean tensile force and variability of each product BEFORE exposure. For the lab study, BEFORE values were used to quantify reductions of ultimate tensile force AFTER exposure to 5576 hours in a salt fog box, an accelerated corrosion device, using conditions described in test method ASTM B 117 [Racin, reference 6]. The same BEFORE values were used in both the lab and field studies in various statistical comparisons and force gain-or-loss calculations AFTER exposure in the salt fog box or at field sites. The **random variable** was **location**, that is, either the specific, local exposure conditions at any of the field sites or the severe exposure to salt fog in the lab.

Table 2. Gabion Wire Mesh Products Tested

product no.	coating [A]	USA wire gage	mesh style	manufacturer
1	zinc	11	welded, square	Hilfiker, CA
2	zinc	9	welded, square	Hilfiker, CA
3	zinc + PVC	10.5	welded, square	Riverdale Mills, MA
4	zinc	11	twisted, hexagonal	Maccaferri, CA
5	zinc + PVC	12	twisted, hexagonal	Maccaferri, CA
6	zinc	11	twisted, hexagonal	Terra Aqua, NV
7	zinc + PVC	12	twisted, hexagonal	Terra Aqua, NV
8 [B]	aluminum	11	twisted, hexagonal	Terra Aqua, NV

[A] On products 1 through 7, zinc was applied by a hot-dip process. Product 3 was welded before it was hot-dipped in zinc, while other products were first coated with zinc and then manufactured as gabion mesh. PVC was applied to wires either by hot-melting or by extrusion and gluing. Intermediate fabrication steps and material mixtures were not reported by manufacturers, because some of the processes are proprietary.

[B] A few Product 8 panels were made for our study. Aluminum coating was applied mechanically.

In our field study, test panels were not placed “in service” as rock-filled gabions, and they did not always get the most severe exposures. Observations included full-scale facilities, so we could qualify our conclusions and recommendations.

WIRE COATINGS

Initially, there were 7 gabion mesh products in both the lab and field studies. Among the products we tested, zinc was the most common sacrificial metallic coating. Zinc is "sacrificed" (chemically converted to oxides, chlorides, sulfides, and/or other compounds) thereby delaying corrosion of the underlying steel wire. Additionally, zinc-coated wire may be coated with polyvinyl chloride (PVC). PVC is a nonconductive plastic coating, which impedes corrosion by attempting to shield the underlying wire from electrolytes. PVC also temporarily shields the relatively soft zinc coating and the underlying harder steel wire from abrasion, the repetitive grinding of relatively harder materials (bedload and suspended sediment) on softer material, plastic and/or zinc and steel.

Details of wire diameter and coating thickness measurements are reported in [Racin, reference 6], on pages 36 through 40. Generally, the zinc was about 1 to 2 mils thick, the standard Class 3 coating required by ASTM A 641. PVC was about 20 mils thick, and no sample had less than 15 mils, the required minimum. For all products, most measured diameters were closer to the lower limits of required wire diameters, within specifications, but about 3 to 4 mils less than the diameters of the respective USA wire gages. See the table on page iv, UNITS and CONVERSION FACTORS.

Limited tests were done on product 8, an aluminum-coated, twisted hexagonal gabion mesh. We were told that the aluminum coating was about 1-mil thick, but no specifications were provided by the supplier. Aluminum-coated gabion mesh was not routinely made or stocked in the US.

Gabion manufacturers inquired if we would also study **galfan** as a sacrificial metallic coating. Galfan is composed of 95 % zinc and a 5 % aluminum-mischmetal alloy that was invented in 1979. In various ASTM standards galfan is designated as **Zn-5 Al-MM**. Galfan appears to be an acceptable coating for corrosion protection and for other properties, when it is used in certain manufacturing processes [Lynch, reference 11]. In 1992, most gabion manufacturers declined to mass-produce gabions with galfan-coated wire, apparently because of its cost, as contrasted to zinc-coated wire. By the mid and late 1990's, a few manufacturers began producing gabions with galfan-coated wire. Caltrans did not fund any additional lab and field work for gabions with any new coatings after 1992, and by the mid 1990's, it was not timely to include galfan-coated wire in our field study.

Epoxy coatings are applied to steel rebar in many reinforced concrete structures. Because most epoxy is brittle after it cures, rebar is first bent into its final shape, and then the epoxy coating is applied. Epoxy acts as an insulator, shielding the underlying steel from contact with electrolyte and/or corrosive elements. One gabion manufacturer considered epoxy coatings for gabions, but the epoxy-coating process was too costly in 1990 [Hilfiker, reference 12]. For gabion walls and other similar metallic wall-building materials in severe exposures, it is usually required to provide clean, free-draining backfill, and/or to use wires or bars with larger diameters, heavier zinc coatings than what is typically specified for gabion wire, and/or to employ cathodic protection schemes. As with aluminum-coated wire, manufacturers did not make any epoxy-coated gabion wire mesh.

2. EXPERIMENTAL DESIGN and PROCEDURES

OVERVIEW

Some of the questions we would try to answer in the field study were :
Where and how long will gabions function with minimal maintenance ? (performance)
Where and how long will gabions last before they must be replaced ? (service-life)

Manufacturers typically provide salt spray data (ASTM B 117), which may indicate that rust stains are seen on zinc-coated mesh after 1000 hours, or that PVC-coated mesh is OK after 3000 hours. Such information does not answer the questions of performance or service-life. We requested test panels for our lab and field experiments from several gabion manufacturers in the US, and they gave us panels from their normal production. To help answer our questions, we placed the test panels on several full-scale gabion facilities, collected soil and/or water data, and then observed, photographed, collected, and tensile-tested gabion wires from test panels and/or full-scale facilities for durations that varied from about one to 15 years. A photographic log (Chapter 3) documents local exposures at sites of test panels and of full-scale gabion facilities, as they may or may not have changed over time. We also maintained site diaries, audio-taped some of our comments, and interviewed people in design, construction, and maintenance. We wanted to develop enough data to help answer our questions about performance and/or service-life of full-scale gabion structures.

WIRE DAMAGE and GABION FAILURE MODES

When investigating the performance and durability of engineering materials, some sort of failure criterion is needed. For our study of gabion mesh, we defined failure as a broken wire. We qualify that we did not expect that a single broken wire would render an entire gabion facility useless. Instead we expected gradual or partial failures of gabion structures, because of the closed-cell construction, the successive joining of individual baskets, and the redundancy of specific geometric arrangements among baskets. So, while some baskets may be damaged, a gabion facility may still function.

At any site where gabions may be built, portions of the structure will normally be exposed to soil, air, water (humidity, precipitation, runoff, groundwater), and sunlight. The natural phenomena of corrosion, particle abrasion, impacts from falling rocks, and impacts from water-borne debris during large storm events will likely affect gabion wire coatings, wear away or break the wires, and perhaps damage parts of gabion facilities. When the confining wire mesh disintegrates or breaks naturally or by other means, gabion rock-fill may be lost or removed from individual baskets, by gravity and/or hydraulic forces. The wire mesh may also be cut and the rock-fill may be removed by vandals. If damaged gabions are not repaired, then protected features will be damaged, and the cost of repairs will likely be much higher than just repairing gabions.

Wire coatings and the underlying wire are abraded when soil particles impinge upon and grind them during events that move and transport sediment. In areas of sparse vegetation, strong winds convey sand particles, which results in abrasion of natural and man-made features. Particle abrasion occurs along ocean and lake shores, where sediment-bearing waves break and wash over shoreline features. In rivers and streams, water (usually storm runoff), conveys the abrading sediment particles. The erosion or wearing away by abrasion of corrosion compounds and of underlying wire in fast-flowing water is called **corrasion** [Bank Protection Committee, reference 13].

Due to cycling daily temperature changes, earth movement, vibrations, and/or rainfall and runoff, rocks on slopes above gabions may break free from their parent formations and fall. Such falling rocks may impact on gabion wires and deform or break them. Storm waves and swift river currents may transport logs, boulders, and other debris, hurling them at gabion structures with enough force to break the wire mesh and disperse the confined gabion rock-fill.

At field sites, we looked for failure of individual gabion wires, for missing rock-fill (partially empty or empty baskets), and for any associated loss of gabion function, that is, erosion (scoured channel inverts, scour holes where energy dissipaters were supposed to be, etc.) or earth confinement features (tilted or misaligned baskets, collapsed sections of walls, slumped embankments, tension cracks and/or sags in the roadway, etc.). We photographed gabion structures periodically or after severe events, and we repaired incidental damage due to sampling wires, that is, when we cut wires from full-scale gabions, we immediately repaired the cut-out zones with new mesh.

EXPERIMENTAL VARIABLES

Test panels were exposed continuously at field sites, as if they were part of the full-scale gabion facility. Thus the **random variable** was **location**. We selected **ultimate tensile force (strength)** as the **fixed variable.** Steel wires are ductile, and while ultimate strength values are typically cited for brittle materials, ultimate tensile strength adequately portrays how much steel was present in corroded gabion wires to resist breakage [Racin, reference 6]. Before we decided on ultimate tensile force, several other variables were considered : the mass-of-zinc (amount of sacrificial metal), loss of wire diameter, and tensile stress (force per unit area). In a prior gabion corrosion study, [Hoover, reference 4], we gained experience handling and processing wire samples. We consulted with experts from the Caltrans Transportation Laboratory [Reed and Aguilar, reference 14] and [Parks, Coats, Carello, and Reis, reference 15] and with metallurgist, Professor Joanna Groza from the University of California, Davis. We discussed various aspects of corrosion, welding, and metallurgy. Because we were dealing with corroded wires, we wanted to minimize sample handling, processing, and measuring, to limit the possibility of altering the wire.

For gabion wire of diameters from USA 12-gage (106 mils) through USA 9-gage (148 mils), in relatively non-corrosive applications, the recommended zinc coating is class 3, 0.8 ounces per square foot of wire surface area (ASTM A 641 specification before metrication). For standard tie wire of diameter USA 13.5-gage (86 mils), the class 3 zinc coating is 0.70 ounces per square foot. PVC may be applied as additional protection in corrosive applications. Because of the various chemical compounds that form in the corrosion process, it would have been difficult to measure the amount of elemental zinc remaining to protect against further corrosion and failure of the underlying wire. And because we would be dealing with corroded wires in various states of corrosion, and in various exposures of air, soil, water and combinations thereof, we did not select mass-of-zinc as a fixed variable.

Loss of wire diameter seemed to be a plausible fixed variable. As we saw in the lab study [Racin, reference 6], the crust of corrosion compounds added to the wire diameter, and that crust was caked-on until it was broken off. We could not measure or forecast where to consistently find the smallest wire diameter, so we did not select loss of diameter as the fixed variable.

Since we were dealing with 5 different wire gages, stress was a strong candidate as the fixed variable. Because stress is force divided by the cross-sectional area, numeric values would be normalized, that is, all the numbers would have the same units, and we could then compare or contrast values among the products. However, we did not select stress as the fixed variable. To get cross sectional area, at least two wire diameters must be measured 90 degrees apart, and then the average diameter is used to calculate the circular cross-sectional area. For newly manufactured and un-corroded wires which are more-or-less uniform, measuring diameters is not a problem, and an average diameter is easily obtained. Based on experience in the lab study, for corroded wires, it was not possible to determine where the smallest diameters were. We tried, but we were unable to find the smallest diameters. We did not expect that corroded gabion wires from field sites would be much different. While noting yield force values and plotting stress-strain curves may have revealed interesting aspects of wire properties (elastic and proportional limits, ductility), to limit experimental error and to improve data reliability, we decided to do fewer measurements and fewer calculations than we did in prior studies.

Therefore, we selected ultimate tensile force as the fixed variable, which correlates directly to the failure mode of gabions. We did rely on loss of wire diameter and color changes of corrosion compounds to decide when to collect samples.

TENSILE TEST PROCEDURES

All tensile tests of both lab and field studies were done on the same tensile testing device in the Translab structural materials testing lab in Sacramento, CA. We used the SATEC machine. It is calibrated annually according to procedures of ASTM E4-98 and SATEC Systems Verification Procedures. Standards are traceable to the National Bureau of Standards [Richards, Cramer, and Weldon, reference 16]. For the range from zero to about 1600 pounds force, the machine was accurate to about 1/4 percent, therefore ultimate tensile forces (maximum values) were not adjusted in any of our charts, tables, or calculations. We followed procedures of ASTM A 370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products. The machine's free-running cross-head movement rate was set at 0.4 inches per minute, the speed that wires were drawn apart until they broke. The same speed was used throughout the entire experiment, regardless of wire diameter. While about half that speed is suggested by ASTM A 370, we tested and compared results of ultimate tensile forces, and we found no significant differences, after running tests at both speeds with several wires from the same strand. The initial distance between the horizontal edges of the machine grips was 2 inches, a distance that was adequate for both corrosion-free and corroded wires. Wire samples were positioned between the machine grips, such that either the twisted zone of twisted mesh or the weld of welded mesh was more-or-less centered. See Figure 2, Photo 1.

Figure 2. Tensile Test and Wire Data BEFORE Exposure

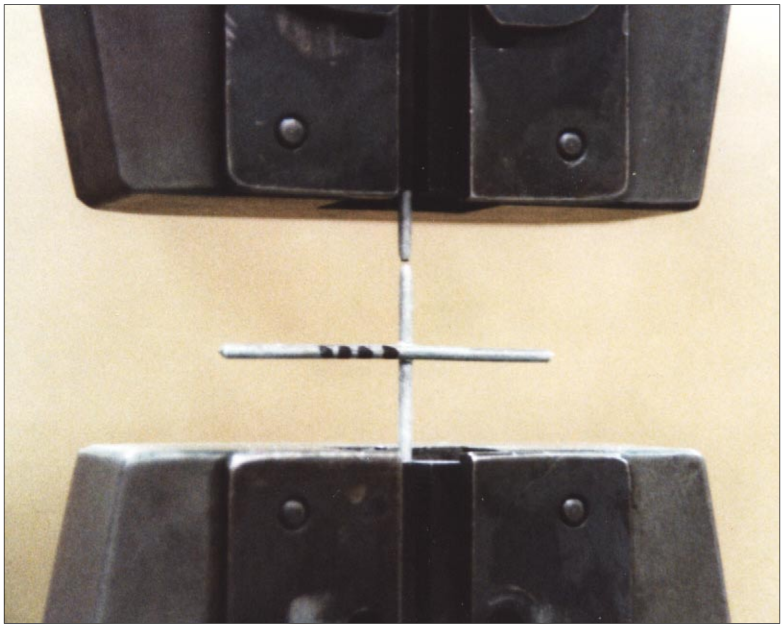
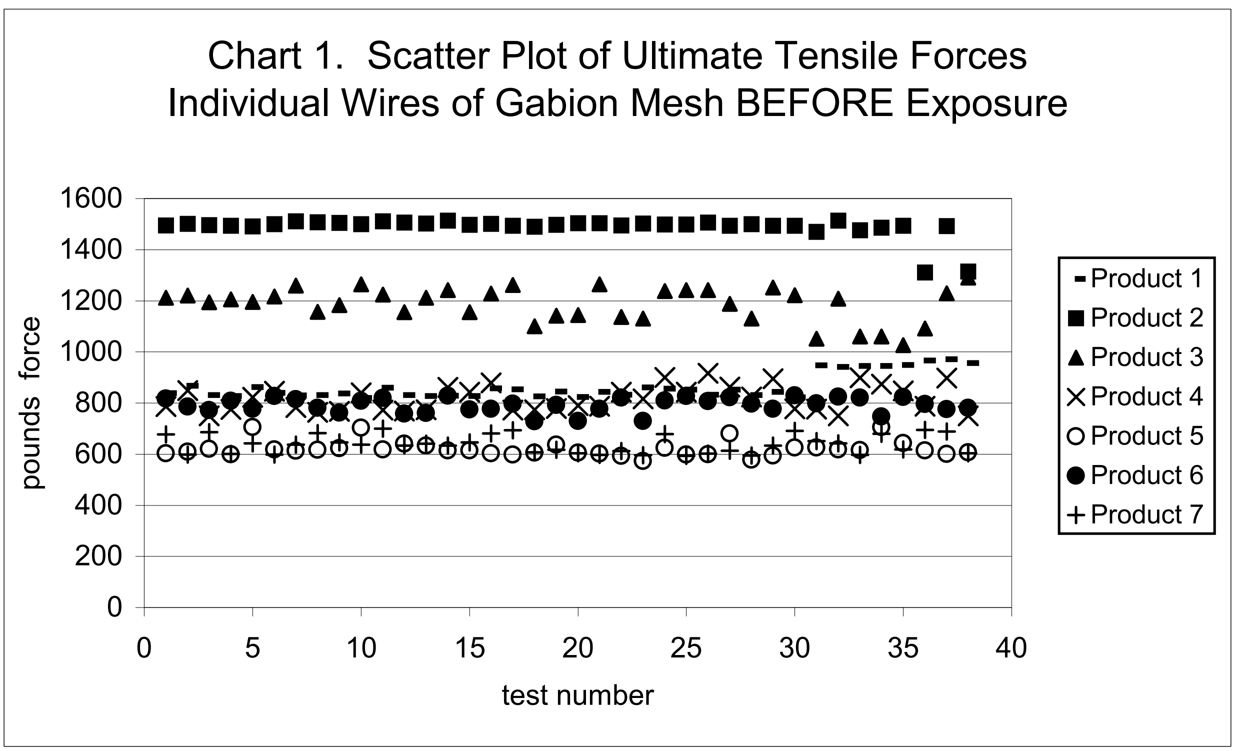


Photo 1. Welded wire in SATEC tensile test machine grips, just after breaking. All breaks were ductile, and wire necked-down before failure. If a wire broke in the machine grips (jaws), then that result was not reported and another test was run. There were only a few jaw breaks among several hundred tensile tests in both the lab and field studies.



BEFORE EXPOSURE - TENSILE TESTS

In the lab study, we broke 38 corrosion-free wires per product from test panels BEFORE exposing comparable test panels to either salt spray or field sites. BEFORE data are the basis for comparisons AFTER exposure. A scatter plot of ultimate tensile force values BEFORE exposure is shown Figure 2, Chart 1. BEFORE mean ultimate tensile force values and variability of each product were calculated. Raw data values and descriptive statistics are in Appendix B. In the lab study, we discussed and documented why we used normal (parametric) statistical tests, as contrasted to using distribution-free (non-parametric) statistical tests [Racin, reference 6, pages 51 and 52], [Crow and Maxfield, reference 17], and [Jung, reference 18].

TEST PANELS - INSTALLATION and WIRE SAMPLE COLLECTION

The size of test panels was the same as in the lab study: 18-inches by 36-inches. Using smaller coupons was considered, but was rejected in favor of the larger samples, which more closely modeled actual gabion products, and gave us the possibility of direct comparisons to prior lab study results, without having to account for scale effects. As we requested, manufacturers gave us several full-sized gabion panels (36-inches by 36-inches) from their normal production runs. We cut the panels in half (18-inches by 36-inches), so there were several sets of half-panels : three sets for the lab study, one set for the control group, and several sets for the field sites. The control group is shown in Photo 2. Initially, all test panels were visibly in excellent condition, free from any defects in the coatings.

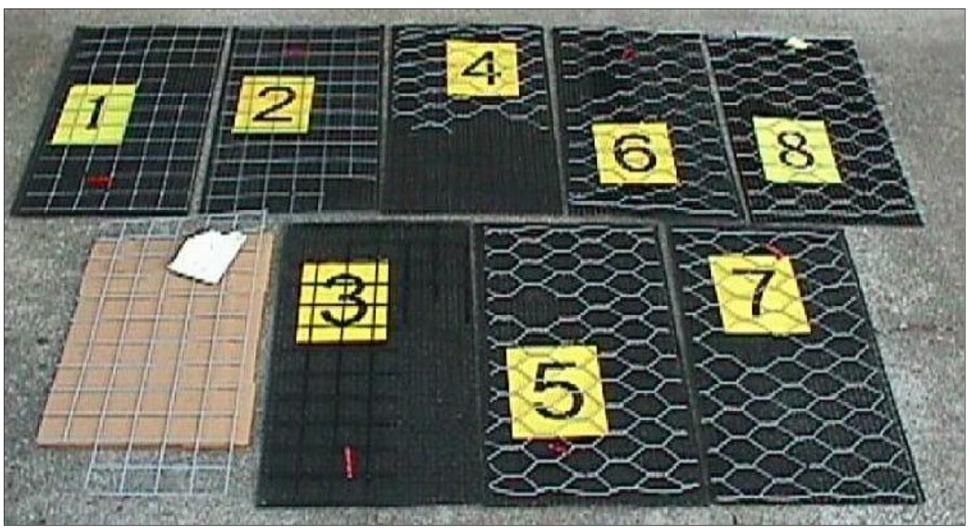


Photo 2. 18-inch by 36-inch CONTROL test panels. Locked indoors and out of sunlight for about 10 years. Wire samples clipped from the control panels were matched against the test panels at field sites and the full-scale facilities. Portions of panels 3 and 4 were used to repair cut-zones of full-scale gabions that were sampled. Products 1, 2, 3, and lower left half panel are welded square-grid gabion mesh. Products 4, 5, 6, 7, and 8 are twisted hexagonal gabion mesh. Products 1, 2, 4, and 6, are zinc-coated, product 8 is aluminum coated, products 3, 5, and 7 are PVC-coated. Black background is core of HDPE (high density polyethylene) geocomposite drain, for insulating test panels from full-scale gabions. Lower left panel was the control for 11-gage gray PVC-coated welded square-grid mesh, road slope protection at site 9. See Table 2 in Chapter 1 for wire gages and manufacturers.

When we installed the test panels at field sites, we insulated them from the full-scale gabion facilities with a sheet of black high density polyethylene, which we salvaged from surplus geocomposite drains. The panels were secured to lids or faces of gabion structures with standard, PVC-coated, 13.5-gage tie wire and black, plastic lock-ties. As the experiment progressed, whenever we visited a site, we photographed the full-scale facility, and we took close-up images of test panel wires. Photo 3 is an example of the close-up photography that we did at one of the sites.

A significant task of the experiment was to collect and tensile test wires from the gabion test panels AFTER various exposure times. We collected wires from full-scale gabions when it was feasible, that is, when we could easily access a panel, cut-out a few wires, and then repair the sampled section, with little or no impact on the continuing performance of the structure. We then tensile-tested the wire samples to failure in the Caltrans structural materials testing lab.

As the field study progressed, the decision process of when to collect wire samples was simplified, contrasted to what we proposed in the lab study. To determine when we should collect wires and tensile-test them, we inspected individual wires. We keyed on color changes, because it is a good clue that corrosion was or was not occurring. We also keyed on loss of wire diameter. Near the end of our experiment, we decided to collect wires and tensile test them, even if they showed very little visible corrosion, because we needed evidence to support our conclusions and recommendations.

WIRE SAMPLE HANDLING

Wire samples received minimal handling, so they were not altered before obtaining a tensile force value. To limit the opportunity for altering wire diameters, we did not clean corroded wires according to the procedure of ASTM A 90, which requires an acid bath. Exposing wires to acid could have reduced the cross section by an unknown amount. We also did not electro-chemically strip corrosion products from wires, also limiting the opportunity to alter wire dimensions. The twisted zone of twisted hexagonal mesh was left intact. On wires with rust and corrosion products, to improve the bite of the tensile-test machine grips, any crusty, powdery, residue was gently twisted off, while wearing soft leather work gloves. Wires with PVC coating were carefully stripped with a pocket knife, so they could be held firmly without slipping out of the machine grips (jaws). To align a twisted gabion wire sample, we bent each end about 60 degrees only once, more or less straightening the wire, so it lined-up in the grips.

AFTER EXPOSURE - TENSILE TESTING and STATISTICAL ANALYSIS

AFTER exposure at the field sites, we collected about 5 or 6 wires and tensile-tested only 4 wires per sample, in some cases just 3 wires. At several of the sites we left the remaining portions of test panels in place for continued exposure. Only collecting 5 or 6 wires and leaving a significant portion of the test panel in the field was done for possible future sampling. Additionally, with fewer samples to break, we limited our competition for the test machine with ongoing contract-compliance testing, and we reduced the amount of time we spent breaking wires. We determined that four wires was adequate for t-testing BEFORE and AFTER mean ultimate tensile forces, and the extra wires we collected were available to break, if there were any breaks in the machine grips (jaws).

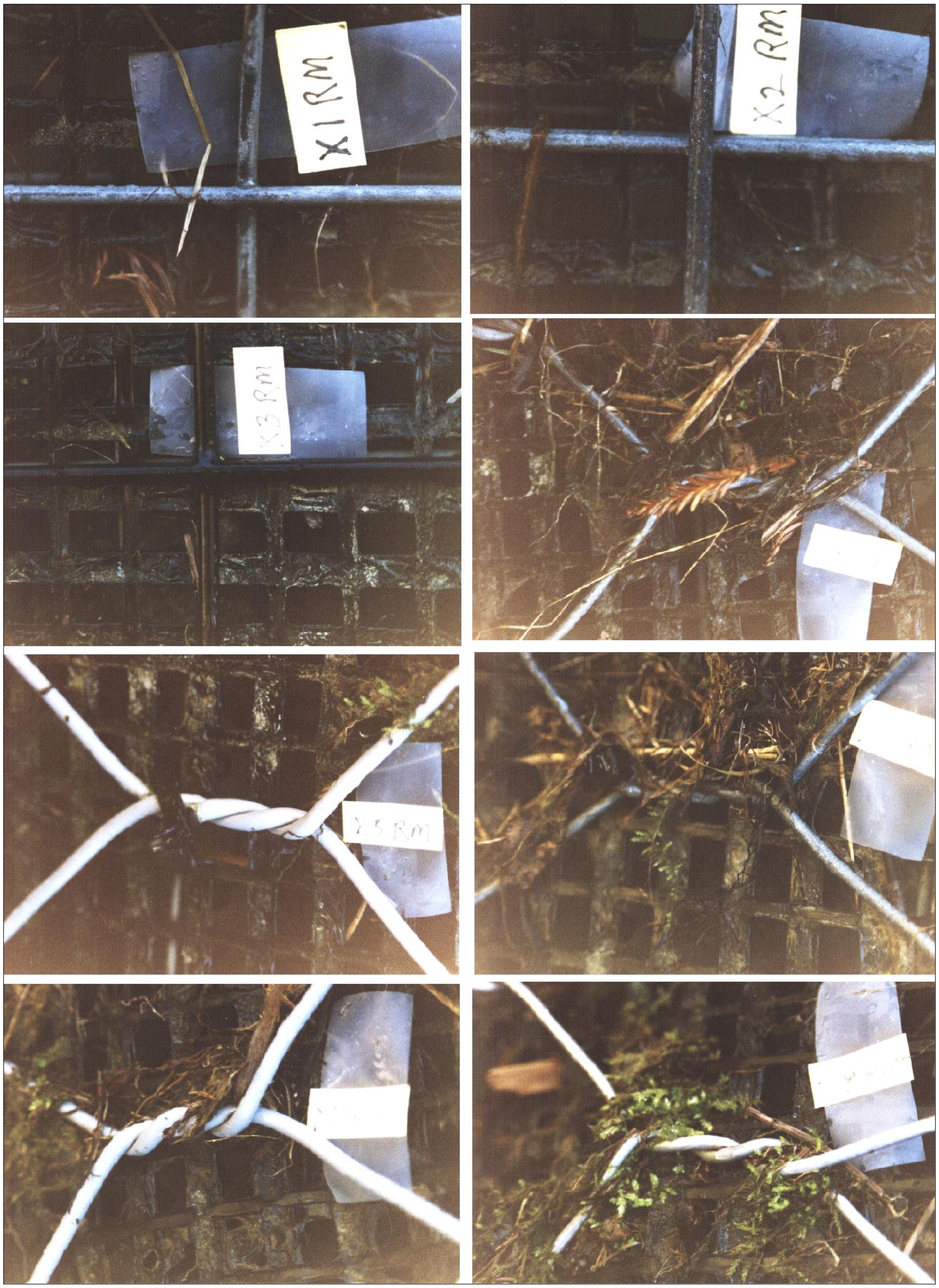


Photo 3. Close-ups of gabion test panel wires. Done for most site inspections. Number of inspections ranged from as few as 1 to as many as 7 visits in about 10 years. From left to right and from top to bottom, images are respectively gabion mesh wires of :

product 1 welded 11-gage zinc-coated
product 2 welded 9-gage zinc-coated
product 3 welded 10.5 gage PVC-coated
product 4 twisted 11-gage zinc-coated
product 5 twisted 12-gage PVC-coated
product 6 twisted 11-gage zinc-coated
product 7 twisted 12-gage PVC-coated
product 8 twisted 11-gage Al-coated

These are images of test panel wires at Site 2, Prairie Creek 01-HUM-101 pm 125.9 on 14 Feb 1996, exposed about 6.25 years. Drift (vegetation remaining after drop in water level) indicates that panels were submerged during recent storm events. Test panels got mostly air exposure, as seen by the dull gray color (zinc carbonate) on zinc-coated products.

For statistical analysis, we used the 5 percent level of significance (size of the rejection region). The null hypothesis of the two-tailed t-test (student t-test) was : **Is there a difference between mean ultimate tensile strength of wire BEFORE and AFTER exposure ?** In the lab study, we used BEFORE values to calculate reductions of ultimate tensile force AFTER exposure to 5576 hours of salt spray. We also used the same BEFORE values in t-tests AFTER exposure at field sites on a product-by-product basis. The BEFORE and AFTER mean ultimate tensile forces and t-test results are tabled in Chapter 3, as part of each site discussion. Individual ultimate tensile force values AFTER exposure were not charted, however, they are listed in Appendices C-1 and C-2. Analyzing BEFORE and AFTER tensile strength data, field observations, and other local site information, helped us to determine whether gabions could, or did, fail due to corrosion and/or other effects.

SITE INFORMATION

Because the random variable was location, we needed site-specific information to help explain any corrosion effects or lack thereof. To determine if there were any confounding factors, like accidents, spills, or vandalism, we interviewed roadway maintenance people. We were cognizant that we were observing gabions among several climatic regions in California, which differ by rainfall patterns and amounts and by daily temperature ranges. However, instead of trying to correlate performance and/or service-life with synoptic (regional) climatic factors, we focused our analysis on local exposures at each site, a “micro-viewpoint”, which we could characterize by limited physical measurements and observations. We looked at soil and water. For soils, we collected samples and measured soil particle sizes, tested minimum soil resistivity, pH, chlorides, and sulfates. For waters, we did occasional instantaneous tests of pH, conductivity, temperature, and sometimes dissolved oxygen. While we did not have precise counts or hydrograph data of storm events, we grossly estimated the relative energy of the water as : waves or storm waves, low or high stream flows. Exposure to sunlight and ultraviolet (uv) radiation was documented via visual inspections. Photo-degraded PVC was a qualitative test that was just observed and not directly quantified, and it is recognized as a sun-bleached, chalky, powdery coating on the PVC, like a light coating of dust. Vegetation (or not) among gabions is documented in photographs.

Because we did not attempt to compare synoptic (broad regional) conditions like differences in rainfall, temperature extremes, or other atmospheric phenomena, the data analysis did not demand direct comparisons between sites or among sites using statistical procedures, like analysis of variance (ANOVA), except for product 8. With product 8, we did some limited among-site comparisons, because of the short duration of exposure, and because we did not have any BEFORE tensile strength data. The aluminized wire producer did not respond to our correspondence and was unavailable via phone or fax (out-of-business by mid-1990’s?). Furthermore, gabion manufacturers were not pursuing any plans at that time to produce aluminum-coated gabion wire mesh.

Conclusions regarding the fixed variable, ultimate tensile force, and the relative performance of full-scale gabion facilities, were arrived at by considering site-specific information and local exposures (the random variable) that appeared to hasten and promote corrosion or the lack thereof.

3. DISCUSSIONS of SITES, OBSERVATIONS, and RESULTS

OVERVIEW of CHAPTER

First we explain some things that are not well-described among various table headings, footnotes, or site discussions. Next we present tables and figures of what we monitored, locations, exposure times, status of test panels or facilities, and soil and water data. While some data may be directly referenced in a site discussion, and while some may not, it does not mean that we did not use the data to arrive at conclusions and recommendations. Next, the validity of the tensile tests is discussed and then we briefly critique the overall experiment. Finally, we present the discussions of each site, observations, test results, and photographic logs. While some photos appear to be repetitious, their different dates are noteworthy, because they document features like vegetative cover, or relatively no changes for comparisons over time. Photo captions emphasize local exposures, gabion performance or failures, procedures, observations, and results. In close-up photos of wires, there is usually a machinist's scale, which is in US units of inches, and it is graduated in 10ths and 100ths of and inch.

EXPOSURE TIMES

In Table 3A, EXPOSURE TIME and STATUS of TEST PANELS and FACILITIES, in the 5th column of exposure times, the units are days, years, and wet seasons. California climate may be classified as arid to semi-arid with notable exception in the northwest. There are generally two seasons: a dry season and a wet season. The dry season is characterized by infrequent rainfall, while the wet season delivers most of the annual precipitation as rain and/or snow. Wet season counts were based on the California water year, which is typically from October 1 through March 31 of the next calendar year, while actual dates of wet and dry seasons may vary. The wet and dry seasons are different in the desert areas of southern California, so at sites 8 and 9 in Death Valley, the wet season counts conform to the months of July through September. Also in Table 3A, the 6th column is labeled "test panel or facility and Caltrans contract no. status". The contract number is given for readers who want to obtain as-built contract plan sheets and typical cross-sections. Contract plans and cross-section details are not included in this report, because any wire damage or gabion failure was not a direct result of any facility configurations. As for "status", OK means that the facility is still functioning well, with no serious threat to the integrity of slopes and/or channels that the facility was built to protect or stabilize. While there may have been some broken wires, we did not count or observe all the wires of the various gabion facilities. "Failed" is discussed in each respective site discussion.

SOIL and WATER DATA

Soil and water data usually helped to affirm the "OK" or "failed" status in Table 3A. In Table 3B, SOIL Test Results, we attempted to classify and name soil samples according the Unified Soil Classification system. Local soils were not necessarily in-situ soils. Instead they often were disturbed soils, which may have been placed there as a result of construction or naturally deposited as a result of sediment transport by storm runoff, wave action, or strong winds. So, if the soil particle size distribution curves in Figures 3-1 through 3-4 indicate that we may have inadvertently mis-named a soil, please note "where the sample was from" in the 1st column. We preferred the simpler common names of soils, which we based on field identifications.

In Table 3C, Instantaneous WATER Measurements Coastal Waters and Ocean, and in Table 3D, Instantaneous WATER Measurements Near Clio 02-PLU-89, the data were used to indicate whether there may have been any electrolyte present, usually via the conductivity value, which helped explain wire corrosion or lack thereof. Before field excursions, we calibrated the YSI portable instruments at the Translab Water Quality and Biology lab as well as on-site, as recommended by the manufacturer, by applying local temperature and elevation corrections.

ULTIMATE TENSILE FORCES - VALIDITY of RESULTS and CRITIQUE

A scatter plot is presented in Figure 2 as Chart 1 on page 10, and it shows the ultimate tensile forces BEFORE exposure of the 7 main products, products 1 through 7. Chart 1 shows relatively uniform values with some variability. BEFORE means and other descriptive statistics are listed in Appendix B. None of the mean ultimate tensile forces, either BEFORE or AFTER exposure were charted, however the values are listed in Tables 3E-1 through 3E-9 and 3E-11, which correspond to sites where we collected and broke wires. Taken as a whole, the AFTER values ranged from virtually no variation to some very large differences, when compared or contrasted to BEFORE values. Large differences occurred where there were severe local exposures.

The tensile test results and student t-tests are tabled and presented with each site discussion. We can restate the null hypothesis of the student t-test as : **Is there a difference between wires BEFORE and AFTER exposure at field sites ?** In Tables 3E-1 through 3E-9 and 3E-11, we sometimes calculated an apparent gain of mean tensile force of wires from a full-scale facility AFTER exposure. This is not what anyone would normally expect. Some of those comparisons are likely NOT valid, unless the test panels and full-scale facilities came from the same production runs. In most cases they did not. We acknowledge that the BEFORE data set was from a relatively small sample of 38 tests, and that the coefficients of variation were less than 6 percent, relatively small variations. Such results may indicate good quality control in manufacturing of wire. However, the BEFORE data represent wire samples from only two gabion panels. It is not likely that those two panels encompassed the range and variability of wires from the universe of wires that were produced for gabions, and especially of the wires with which the full-scale gabion facilities were actually built. While we used the 5 percent level of significance, (size of the rejection region), we feel there may be instances of statistical errors of Type I, where we rejected the null hypothesis when it was true, and also of Type II, where we may have accepted the null hypothesis when it was false.

Some of the gains in mean ultimate tensile force AFTER exposure may indeed be valid. When there was a relatively small apparent gain, there a few reasonable explanations to consider. One is the possibility of strain aging [Reed and Aguilar, reference 17]. Another is that there were larger wire diameters in the full-scale facility as opposed to the test panels. In prior research, it was reported that within test panels among products 1 through 7, there were average diameters that were less than the minima that are required by the Caltrans material specifications [Racin, reference 6]. Another explanation for small apparent gains in ultimate tensile force is the likelihood of different elemental mixtures from one heat (batch of steel) to the next. Various scrap metal products may be used to manufacture the wire, so some batches may produce stronger steel. When there were really large gains in ultimate tensile force, we can assume that all of these factors contributed to the relatively large values.

A flaw of the statistical design is the relatively small data sets of BEFORE and AFTER tensile forces. Another flaw we acknowledge is that we deployed relatively few test panels at the field sites, which did not always account for some of the severe local exposures that we observed. However, along with soil and water data, diaries, observations of both test panels and full-scale facilities, and the photographic logs, the results are still useful for estimating gabion performance and service life, and for determining where gabions may serve their intended function, and where they may require ongoing maintenance or replacement.

OVERVIEW of DISCUSSIONS of SITES

Among the discussions, we present a little more information for sites that showed corrosion or other effects, than for sites where there were no apparent changes. We first inspected sites 1 through 6 in late 1990 and early 1991, about a year after we installed the test panels. We revisited the sites several more times and photographed wires and the facilities, measured water characteristics, and collected soil samples. We documented if there were any failures or other noticeable effects, like accidents or vandalism, or if there were no apparent changes. As the study progressed, we added 8 more sites with full-scale gabion facilities to observe and document the effects of different local exposures. Only site 7 had test panels of products 4 and 5 from a prior study [Hoover, reference 4] and [Racin, reference 5].

During inspections, we keyed on color change as the primary indicator of corrosion, by matching pieces of un-corroded control panel wires, against test panels and full-scale facilities. When they are wet, corrosion products appear less reflective and somewhat dulled, as contrasted to dry samples or facilities. At site 5, samples were not visible because they were submerged in the wetland and hidden by dense vegetation. There was a black, slimy precipitate clinging to the zinc-coated wires of the energy dissipater and zinc-coated test panels. So, to detect any changes at site 5, we felt ("finger-mic'd") the submerged wires and compared them to samples of the control panel wires. We were trying to feel if there were a loss of wire diameter.

We deviated somewhat from the work plan that was proposed in the lab study, which called for periodically collecting and tensile testing wires. Instead, we waited for as long as possible to collect wire samples, so we collected samples toward the end of the study and when our funds were nearly spent.

TABLE 3A. EXPOSURE TIME and STATUS of TEST PANELS and GABION FACILITIES					
site number name district-county-route post mile direction or landmark	product number	installed test panels or built facility	collected samples or inspected	exposure time days years wet seasons	test panel or facility Caltrans contract no. status
1 White Slough 01-HUM-101 70 northbound	1, 2, 3, 4, 5, 6, 7	29 Nov 1989	3 Dec 1992	1040 2.85 2	test panels on channel slope, intertidal zone all PVC panels OK, all zinc panels corroded collected panels
1 White Slough 01-HUM-101 70 southbound	1, 2, 3, 4, 5, 6, 7	29 Nov 1989	24 May 1999	3463 9.48 10	test panels on channel slope, intertidal zone all PVC panels OK, all zinc panels > 50 % corroded
1 White Slough 01-HUM-101 70 southbound	8	17 Dec 1992	24 May 1999	2349 6.43 7	test panel on channel slope, intertidal zone Al panel > 50 % corroded
2 Prairie Creek 01-HUM-101 125.9 Redwood Park near Orick	1	1 Nov 1988	27 May 1999	3860 10.57 11	retaining wall contract 01-194424 50' failed in 9th wet season partial sample collected
2 Prairie Creek 01-HUM-101 125.9 Redwood Park near Orick	1, 2, 3, 4, 5, 6, 7	28 Nov 1989	26 May 1999	3466 9.49 10	test panels on wall facing the creek OK collected panels
2 Prairie Creek 01-HUM-101 125.9 Redwood Park near Orick	8	17 Dec 1992	26 May 1999	2351 6.44 7	test panel on wall facing the creek OK collected panel
3 Redwood Park Bypass 01-HUM-101 127 southbound	4	1 Nov 1988	26 May 1999	3859 10.57 11	open channel downdrain contract 01-194424 OK not sampled
3 Redwood Park Bypass 01-HUM-101 127 southbound	1, 2, 3, 4, 5, 6, 7	28 Nov 1989	26 May 1999	3466 9.49 10	test panels on side slope facing channel OK collected samples
3 Redwood Park Bypass 01-HUM-101 127 southbound	8	17 Dec 1992	26 May 1999	2351 6.44 7	test panels on side slope facing channel OK collected samples

TABLE 3A. EXPOSURE TIME and STATUS of TEST PANELS and GABION FACILITIES					
site number name district-county-route post mile direction or landmark	product number	installed test panels or built facility	collected samples or inspected	exposure time days years wet seasons	test panel or facility Caltrans contract no. status
4 Mohawk Creek 02-PLU-89 5.3 Mohawk Valley near Clio	4	31 Aug 1989	17 Aug 1999	3621 9.91 10	slope protection mattress contract 02-222904 OK not sampled
4 culvert inlet invert apron 02-PLU-89 5.2 Mohawk Valley near Clio	4	31 Aug 1989	20 Oct 1998	3341 9.15 9	invert mattress contract 02-222904 corroded collected samples
4 overflow zone 02-PLU-89 5.2 Mohawk Valley near Clio	1, 2, 3, 4, 5, 6, 7	3 Nov 1989	20 Oct 1998	3277 8.97 9	test panels on mattress lids at toe of slope OK collected samples
4 overflow zone 02-PLU-89 5.2 Mohawk Valley near Clio	8	2 Dec 1992	20 Oct 1998	2152 5.89 6	test panel on mattress lid at toe of slope OK collected sample
5 energy dissipater 02-PLU-89 4.7 Mohawk Valley near Clio	4	31 Aug 1989	17 Aug 1999	3621 9.91 10	wetland energy dissipater contract 02-222904 corroded not sampled
5 energy dissipater 02-PLU-89 4.7 Mohawk Valley near Clio	1, 2, 3, 4, 5, 6, 7	3 Nov 1989	17 Aug 1999	3574 9.79 10	test panels at wetland energy dissipater PVC panels OK zinc panels corroded collected samples
5 energy dissipater 02-PLU-89 4.7 Mohawk Valley near Clio	8	2 Dec 1992	17 Aug 1999	2449 6.70 7	test panel at wetland energy dissipater OK collected sample
6 Little Norway 03-ED-50 63.9 eastbound passing lane elev. 7000 feet	1	1 Jun 1988	4 Aug 1999	4082 11.18 11	retaining wall contract 03-323004 buried lids corroded wall face OK collected sample

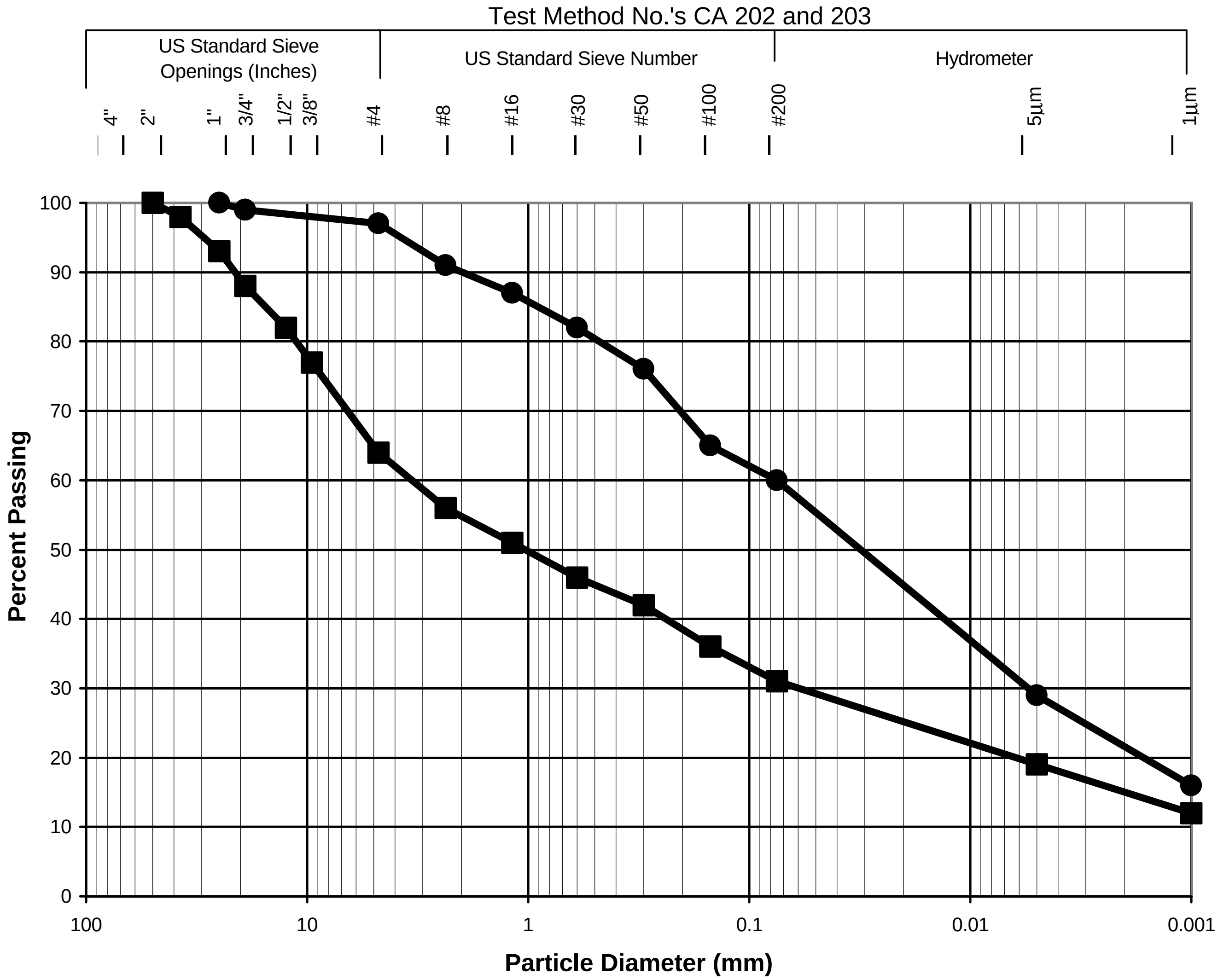
TABLE 3A. EXPOSURE TIME and STATUS of TEST PANELS and GABION FACILITIES					
site number name district-county-route post mile direction or landmark	product number	installed test panels or built facility	collected samples, inspected	exposure time days years wet seasons	test panel or facility Caltrans contract no. status
6 Little Norway 03-ED-50 63.9 eastbound passing lane elev. 7000 feet	1, 2, 3, 4, 5, 6, 7	7 Nov 1989	4 Aug 1999	3557 9.74 10	test panels on face of wall OK collected samples
6 Little Norway 03-ED-50 63.9 eastbound passing lane elev. 7000 feet	8	2 Dec 1992	4 Aug 1999	2436 6.67 7	test panels on face of wall OK collected samples
7 mattress under north RSP 05-MON-1 7.5 beach, Pacific Ocean near Alder Creek	5	1 Dec 1985	4 Nov 1998	4722 12.93 13 (16)	mattress under 8-ton RSP contract 05-307814 mattress remnant found and sampled 1998. Rock displaced during 2000-2001 wet season and some mattresses exposed. OK (May 2001)
7 south and north walls 05-MON-1 7.7 and 8.1 beach, Pacific Ocean near Alder Creek	5	1 Dec 1985	4 Nov 1998	4722 12.93 13 (16)	retaining walls contract 05-307814 some corrosion not sampled OK (May 2001)
7 south wall test panels 05-MON-1 7.7 beach, Pacific Ocean near Alder Creek	4 and 5	15 Oct 1986	4 Nov 1998	4403 12.05 12	test panels on wall facing ocean, zinc panels corroded PVC OK, collected samples
7 north wall test panels 05-MON-1 8.1 beach, Pacific Ocean near Alder Creek	4 and 5	15 Oct 1986	4 Nov 1998	4403 12.05 12	test panels on wall facing ocean zinc panels corroded, PVC OK collected samples
7 north wall BLAZED panel 05-MON-1 8.1 beach, Pacific Ocean near Alder Creek	5	15 Oct 1986	4 Nov 1998	4403 12.05 12	test panel on wall facing ocean, at BLAZED PVC wire was deeply corroded collected sample

TABLE 3A. EXPOSURE TIME and STATUS of TEST PANELS and GABION FACILITIES					
site number name district-county-route post mile direction or landmark	product number	installed test panels or built facility	collected samples or inspected	exposure time days years wet seasons	test panel or facility Caltrans contract no. status
8 Furnace Creek Wash 09-INYO-190 122.3 Death Valley National Park	like 1 with gray PVC	1 Apr 1994	9 Jun 1998	1530 4.19 4	mattress slope protection contract 09-234804 OK collected sample
9 Gower Wash 09-INYO-190 115.3 near Zabriskie Point Death Valley National Park	4	assumed 8 Jun 1983	9 Jun 1998	5472 15 15	mattress slope protection and channel invert, job by Caltrans maintenance OK, some failed baskets collected sample
10 Sawmill Creek 02-TRI-299 63.8 eastbound	1	1 Nov 1987	28 May 1999	4227 11.57 12	downdrain open channel contract 02-219604 OK not sampled
11 Cholame Creek 05-SLO-46 48.3 westbound	4	1 Sep 1996	3 Nov 1998	794 2.17 2	check dam contract 05-428024 OK collected sample
12 Ulatis Creek bridges 23-0052 left & right 04-SOL-80 R42.8	7	1 Oct 1996	5 Jun 1997	248 0.68 1	retaining walls, mattress slope protection contract 04-239804 OK, some vandalism not sampled
13 Lime Kiln Creek 05-MON-1 21 Lime Kiln Beach private campground	5	19 Nov 1988	1 March 1995	2293 6.28 7	gabion mattress at toe of concrete crib wall contract 05-327404 failed, wave attack not sampled
13 Lime Kiln Creek 05-MON-1 21 Lime Kiln Beach State Park		1 Oct 1995	14 March 2000	1627 4.45 5	no gabions, wall buttressed with 8-ton RSP contract 05-409304 OK after a few winter storms
14 San Gregorio Creek 04-SM-84 7.2 westbound	5	1 Sep 1999	20 Dec 2000	447 1.22 1	retaining wall with wood fascia, mattress along toe covered with coir logs contract 04-058304 OK not sampled

Table 3B. SOIL Test Results						
site number name where sample was from district-county-route post mile	field classification, group symbol and Unified name [A]	pH [B]	minimum resistivity ohm-cm [B]	soluble sulfate ion ppm [C]	soluble chloride ion ppm [D]	Atterberg Limits LL PL PI [E]
1 White Slough streambank intertidal zone 01-HUM-101 70	blue-gray clay, OL sandy organic clay	6.4	75	2040	7980	44 28 16
3 Redwood Park Bypass uphill of downdrain 01-HUM-101 127	red clay & gravel, GC clayey gravel with sand	5.1	4975	74	21	31 23 8
4 Mohawk Valley bank soil at overflow zone near 36" culvert inlet invert 02-PLU-89 5.2	brown silty sand, SM silty sand with gravel	6.4	4767	measured 0	30	not plastic
5 Mohawk Valley meadow bottom soil near 60" culvert inlet 02-PLU-89 4.7	black silty sand, SM silty sand with gravel	6.9	4644	20	measured 0	not plastic
5 Mohawk Valley soil in wetland near 60" culvert outlet and energy dissipater 02-PLU-89 4.7	black silty sand, SM silty sand	6.3	3644	measured 0	measured 0	not plastic
7 Pacific Ocean beach intertidal zone 05-MON-1 7.5	gray sand & gravel, SP poorly graded sand with gravel	8.9	220	240	1050	not plastic
11 Cholame Creek streambed at check dam 05-SLO-46 48.3	white silty sand, SP poorly graded sand	8.7	455	390	230	not plastic
8 Furnace Creek Wash desert wash (arroyo) 09-INYO-190 122.3	tan gravel & sand, SW well graded sand with gravel	9.0	4200	likely low, pH >5 and high resistivity	likely low, pH >5 and high resistivity	not plastic
9 Gower Wash desert wash (arroyo) 09-INYO-190 115.3	gray sand & gravel, SW well graded sand with gravel	8.6	2600	likely low, pH >5 and high resistivity	likely low, pH >5 and high resistivity	not plastic

[A] group symbol and name based on ASTM D 2487, the Unified Soil Classification System, which uses lab test results of Atterberg Limits and soil particle size distribution curves. See Figures 3-1, 3-2, 3-3, and 3-4.
[B] Test Method No., California 643
[C] Test Method No., California 417
[D] Test Method No., California 422
[E] Test Method No., California 204 LL = liquid limit PL = plastic limit PI = plasticity index

Figure 3-1. Soil Particle Size Distribution Curves, Sites 1 and 3



GRAVELS		SANDS			SILT	CLAY
Coarse	Fine	Coarse	Medium	Fine		

Sample ID:
- ● Site 1. bank soil intertidal zone, White Slough near College of the Redwoods
- ■ Site 3. soil by downdrain, Redwood Park Bypass near Prairie Creek

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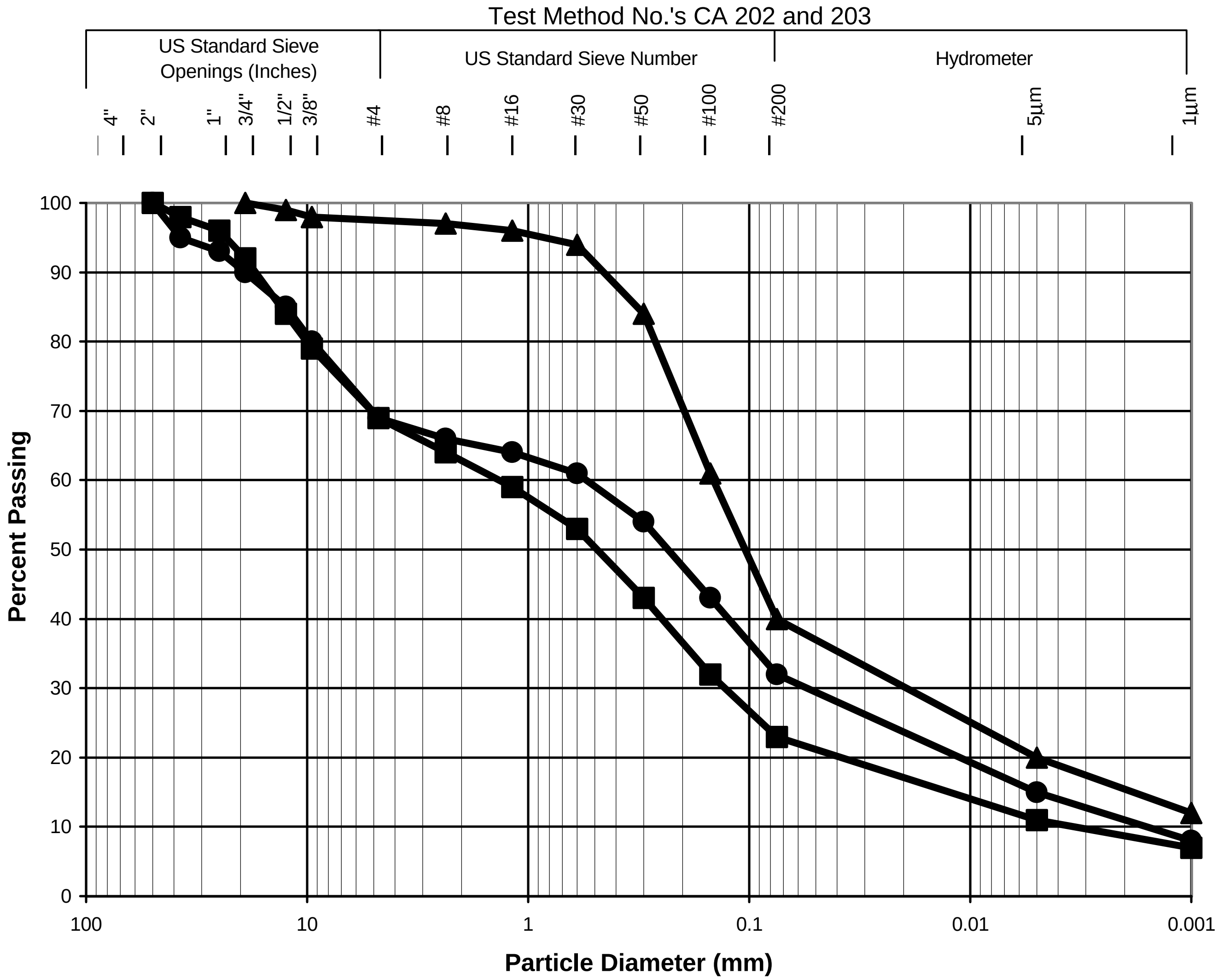
Geotechnical Laboratory

Project: Gabion Corrosion Study

D-Co-Rt: 01-Hum-101 70 and 127

Sampled: 13 and 14 Feb 1991

Figure 3-2. Soil Particle Size Distribution Curves, Sites 4 and 5



GRAVELS		SANDS			SILT	CLAY
Coarse	Fine	Coarse	Medium	Fine		

Sample ID:

- ● Site 4. bank soil at overflow zone near 36" culvert inlet invert apron
- ■ Site 5. meadow soil near double 60" bituminous culvert inlet
- ▲ Site 5. wetland soil at outlet of dbl. 60" bit. culvert and energy dissipater

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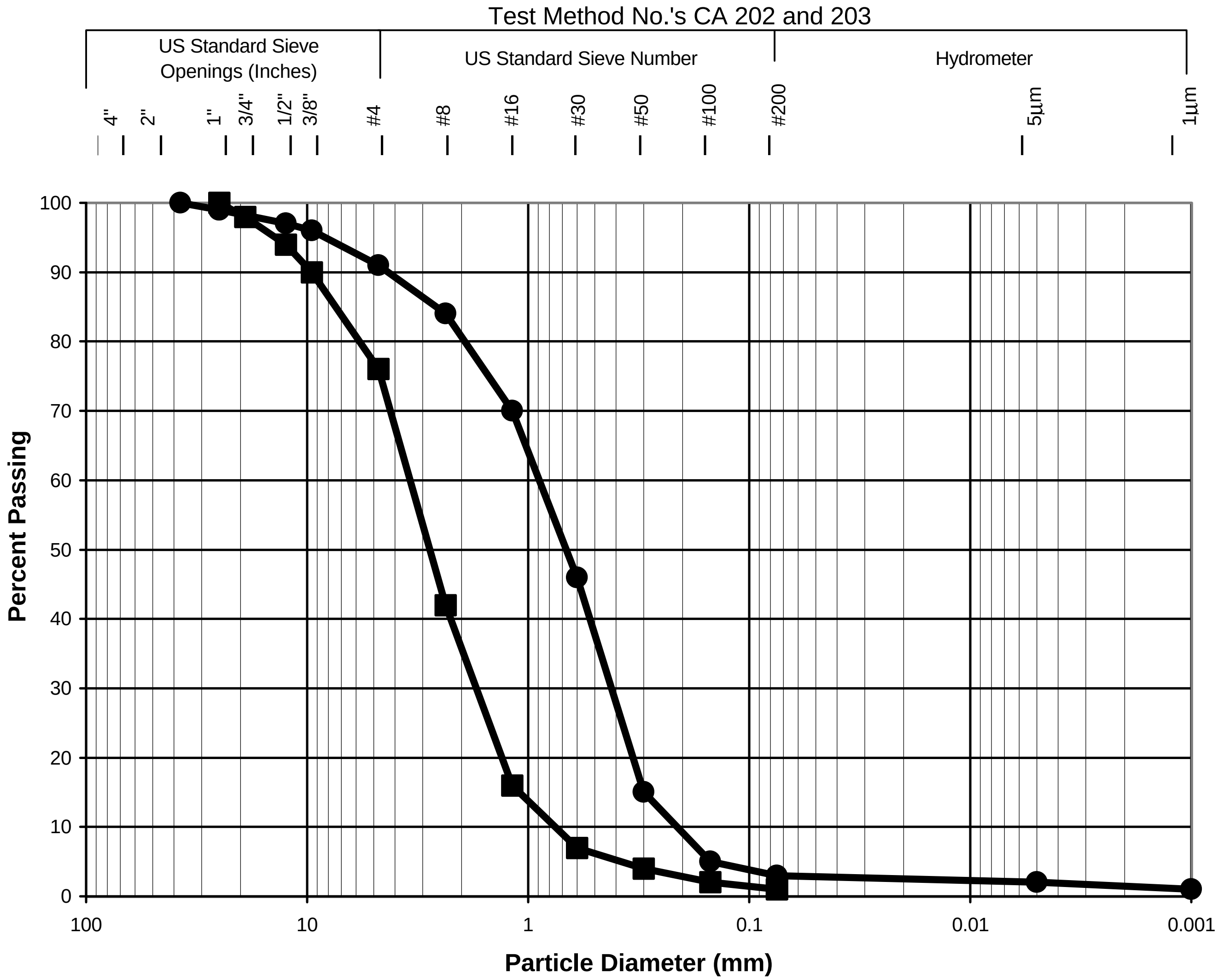
D-Co-Rt: 02-Plu-89 5.2 and 4.7

Sampled: Nov. 3, 1989

Figure 3-3. Soil Particle Size Distribution Curves, Sites 7 and 11



GRAVELS		SANDS			SILT	CLAY
Coarse	Fine	Coarse	Medium	Fine		

Sample ID:
- Site 11. channel bottom soil at upstream check dam in Cholame Creek
- Site 7. beach sand in intertidal zone of Pacific Ocean near Alder Creek

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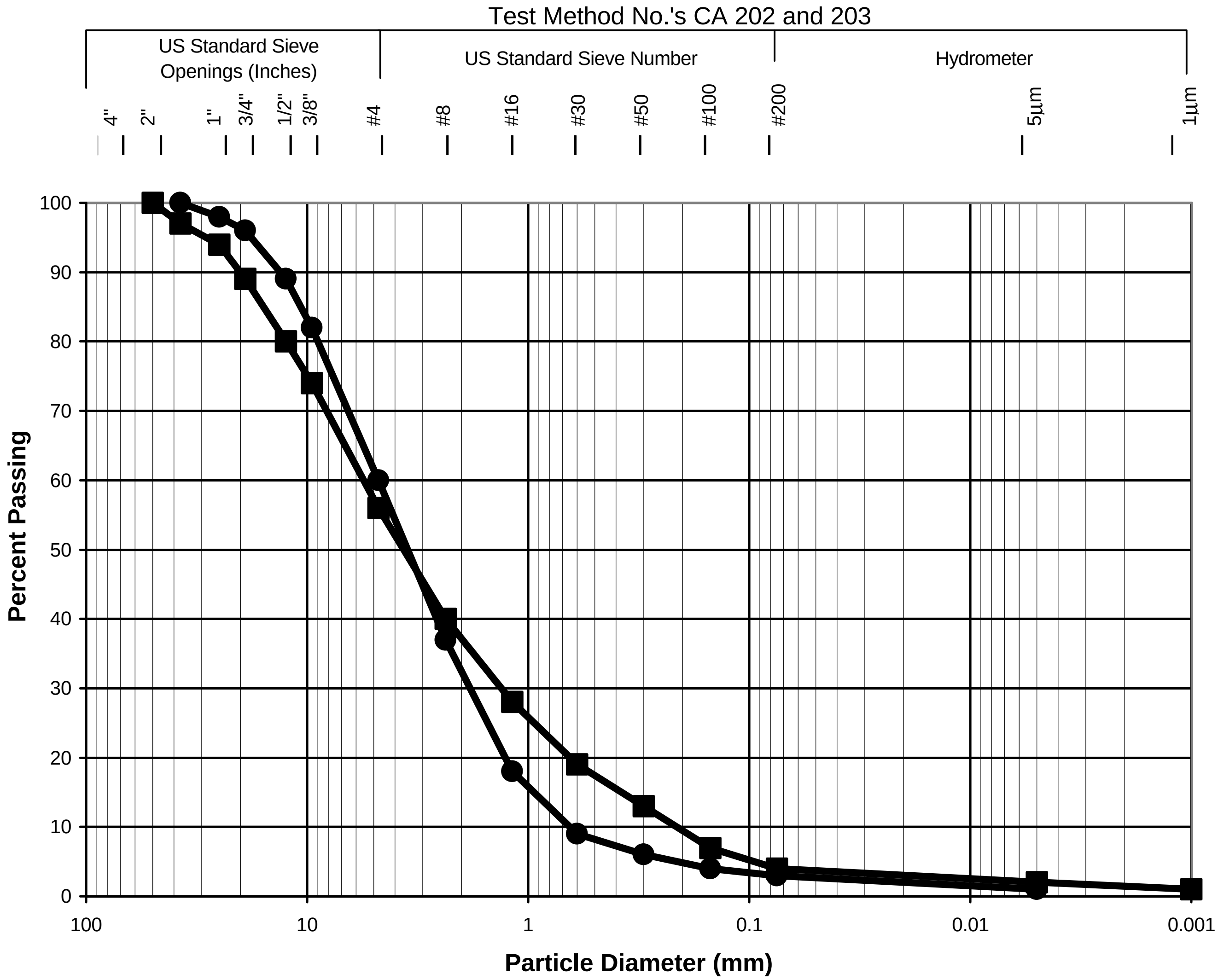
Project:	Gabion Corrosion Study
D-Co-Rt:	05-SLO-46 and 05-Mon-1
Sampled:	3 and 4 Nov 1998

Figure 3-4. Soil Particle Size Distribution Curves, Sites 8 and 9



GRAVELS		SANDS			SILT	CLAY
Coarse	Fine	Coarse	Medium	Fine		

Sample ID:
- ●— Site 8. channel bottom, Furnace Creek Wash, Death Valley
- ■— Site 9. channel bottom, Gower Wash at Zabriskie Point, Death Valley

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Caltrans

Project: Gabion Corrosion Study

D-Co-Rt: 09-INYO-190 122.3 & 115.3

Sampled: Jun. 9, 1998

Table 3C. Instantaneous WATER Measurements Coastal Waters and Ocean							
[meter A or B] site number water body probe location	time date	tide or depth velocity flowrate [C]	water temperature degrees Centigrade	salinity percent [D]	conductivity micromhos/cm [E]	dissolved oxygen percent	dissolved oxygen mg/l
[A] site 1 White Slough near surface	0705 24 Jun 1993	ebb 3 hrs before low	15	10.5	14,500	not measured	not measured
[A] site 1 White Slough near surface	0830 16 Nov 1993	flow 2 hrs after low	9	6	8000	not measured	not measured
[A] site 1 White Slough near surface	1110 16 Nov 1993	flow 1.5 hrs before high	10	12.5	15,000	not measured	not measured
[A] site 1 White Slough 0.5ft from surface	noon 2 May 1995	flow 3.5 hrs after low	17	3.5	5000	not measured	not measured
[A] site 1 White Slough near bottom	noon 2 May 1995	flow 3.5 hrs after low	14	10	15,000	not measured	not measured
[A] site 2 Prairie Creek near bottom	1500 23 Jun 1993	0.8 foot 1.5 fps < 14 cfs	13.5	0	55	not measured	not measured
[A] site 2 Prairie Creek near bottom	1340 16 Nov 1993	0.5 foot < 0.5 fps >3 cfs	7.9	0	60	not measured	not measured
[A] site 2 Prairie Creek near bottom	1800 2 May 1995	> 1 foot 3 fps > 50 cfs	11	0	45	not measured	not measured
[B] site 7 Pacific Ocean surf zone	1330 4 Nov 1998	ebb 3 hrs after high	13.4	3.24	38,600	92	7.86

[A] Used YSI analog meter, which measured conductivity in micromhos/cm.
The unit of resistivity is ohm. Since conductivity = 1 / resistivity, the unit was called “mho”.
Both YSI meters were calibrated on-site (temperature corrected), as recommended by the manufacturer.
[B] Used YSI 85 digital meter. This instrument was also calibrated for local elevation, sea level.
[C] All instantaneous measurements represent non-storm tides or creek flow rates.
[D] YSI 85 meter reported ppt (parts per thousand). ppt x 100/1000 = percent
[E] YSI 85 meter reported microsiemans/cm 1 microsieman/cm = 1 micromho/cm

Table 3D. Instantaneous WATER Measurements Near Clio 02-PLU-89							
[meter A or B] site number water body probe location	time date	depth velocity flowrate [C]	water temperature degrees Centigrade	salinity percent [D]	conductivity micromhos/cm [E]	dissolved oxygen percent	dissolved oxygen mg/l
[A] next to 4 36" culvert inlet invert apron near surface	1600 22 Jun 1993	0.08 foot < 1 fps 0.08 cfs	25	0	95	not measured	not measured
[A] near 4 Mohawk Creek near surface	1630 22 Jun 1993	0.30 foot 2 fps 6 cfs	24	0	80	not measured	not measured
[A] 5 wetland near surface and energy dissipater	1720 22 Jun 1993	0.5 foot > 0 fps > 0 cfs	22	0	130	not measured	not measured
[B] next to 4 36" culvert inlet invert apron near surface	1000 20 Oct 1998	stagnant	4.6	0.01	74.2	14.4	1.78
[B] near 4 Mohawk Creek near surface	1010 20 Oct 1998	0.42 foot 3 fps > 8 cfs	10.8	0.01	114.5	76	8.40
[B] 5 wetland near surface and energy dissipater	0945 20 Oct 1998	stagnant	4.1	0.01	97.4	20.4	2.52

[A] Used YSI analog meter, which measured conductivity in micromhos/cm.
The unit of resistivity is ohm. Since conductivity = 1 / resistivity, the unit was called “mho”.
Both YSI meters were calibrated on-site (temperature corrected), as recommended by the manufacturer.
[B] Used YSI 85 digital meter. This instrument was also calibrated for local elevation, sea level.
[C] All instantaneous measurements represent non-storm flow rates.
[D] YSI 85 meter reported ppt (parts per thousand). ppt x 100/1000 = percent
[E] YSI 85 meter reported microsiemans/cm 1 microsieman/cm = 1 micromho/cm

SITE 1

The exposure of Site 1 is a coastal, tidally-influenced channel, White Slough, which is submerged at high tide with saline and brackish waters. There is little wave action. White Slough flows about ½ mile through the Humboldt Bay National Wlidlife Refuge to Humboldt Bay, which connects to the Pacific Ocean. There are two daily tides, and velocities were estimated as 5 feet per second and less. Such velocities do not usually cause significant bank scour. Along its entire length, channel side slopes do not have any vegetation below high tide elevation. The average annual rainfall as measured at Eureka is about 40 inches. There is likely some erosion from raindrop impact during storms at low tides. Despite the low velocities, there is a gradual loss of upper slope soil. As water level drops, excess water pressure pushes and dislodges very fine-grained surface soil particles, some of which may get suspended and conveyed by tides, depositing elsewhere. After about 10 years, the net effect of the erosion process was aggradation of the lower slope, such that gabion test panels were buried. The upper slope receded about one foot laterally. We measured water properties that characterize this tidal site. See Table 3C. And we measured some soil properties. See Table 3B and Figure 3-1.

There are no full-scale gabion facilities at this site. We placed 2 sets of test panels directly on the channel side slopes in the intertidal zone, that is, between high and low tide elevations. Test panels were just beyond the wingwalls of the White Slough box culvert (about 12 feet wide), which closely matches the channel bottom width. One set was near the northbound roadway, and the second set was near the southbound roadway. We tied the panels to a 5/16-inch nylon rope and tossed them onto the muddy channel slopes. See Table 3A for exact installation dates and exposure times. After about 18 months, we found the northbound test panels high-and-dry on the bank, above high tide elevation. District 1 maintenance people related that a convict brush removal crew disturbed the panels. However, the panels were still tied to the nylon tether, and they were in good physical shape, so we reset them. We estimated that the test panels were out of place for 60 days, so the exposure time listed in Table 3A is 1040 days, not 1100 days.

After nearly 3 years, a layer of fine-grained, saturated soil particles, (bay mud), encased and partially covered the bottom halves of panels, such that corrosion products did not erode away in the tidal current. The top halves of panels were corraded. We collected and removed all the northbound test panels. There were a few barnacles and other biota attached to both zinc-coated and PVC-coated test panels. We tensile-tested wires, from top, middle, and bottom zones of the panels. Tensile and t-test results are in Table 3E-1. Zinc-coated wires lost 20 percent or more of their strength, as measured by reduced ultimate tensile forces. There were about 50 of 120 breaks within the twisted zone of twisted mesh, likely due to cold-working of wire during gabion manufacture. Twisted mesh wires at this site held soil and water in the twist. Welded wires never broke at the weld, however, there were 21 of 90 breaks less than 3 diameters from the weld. This result was expected and paralleled the behavior in the lab study. Welds are at a higher energy state (cathodes), than the inter-weld segments of wire (anodes), where most breaks occurred. PVC-coated wires did not lose any tensile strength. An aluminum panel was placed after 3 years.

After 9-and-½ years, there was about 8-inches of bay mud covering the initial test panels of the initial 7 products. We carefully dug through mud, however, we collected only PVC-coated panels. The Al-coated and zinc-coated panels were mostly disintegrated, corrosion compounds were blended-in with the mud, and some shells of marine biota were very close or attached to some wires. Only PVC-coated wires were tensile and t-tested, and they showed no loss of strength. PVC was disbonded from wires due to daily temperature changes, and there was corrosion near the cut ends of panels and where PVC was damaged. Saline water and fine-grained, saturated soil with high chlorides, were the reasons for aggressive corrosion. Although velocities are low, corrosion compounds eroded where exposed to tides. See photos 4 through 32 and captions for details of local exposures and effects at Site 1.

TABLE 3E-1. White Slough Tensile and t-Test Results

A	B	C	D	E	F
1 White Slough	1	2.85	not mic'd	YES	681 863 5.63 -21.1
01-HUM-101 70	2		not mic'd	YES	1024 1488 2.88 -31.2
northbound	3		not mic'd	NO	1210 1185 5.69 NCD
	4		not mic'd	YES	534 816 6.12 -34.6
test panels	5		not mic'd	NO	628 621 5.02 NCD
	6		not mic'd	YES	627 792 3.70 -20.8
	7		not mic'd	NO	642 638 5.61 NCD
1 White Slough	1	9.48	not mic'd	ntd	> 50% wire disintegrated
01-HUM-101 70	2		not mic'd	ntd	> 50% wire disintegrated
southbound	3		126 129 133	NO	1118 1185 5.69 NCD
	4		not mic'd	ntd	> 50% wire disintegrated
test panels	5		101 106 108	NO	622 621 5.02 NCD
	6		not mic'd	ntd	> 50% wire disintegrated
	7		101 101 104	NO	607 638 5.61 NCD
	8	6.43	not mic'd	ntd	> 50% wire disintegrated

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Column A site number, name, Caltrans District-county-route post mile, direction or landmark, test panel or kind of gabion facility

Column B product number

Column C exposure time, years

Column D 1. 3 numbers in mils (1 mil = 1/1000 inch):
1st number is minimum allowable wire diameter with zinc coating.
Next 2 numbers are low and high of 4 diameters from 2 wires, before tensile test. Diameters were measured with flat micrometer.

or 2. "not mic'd" (not measured with micrometer) due to corrosion crust or pits, or just not measured.

Column E

1. NO or YES, the answer to the question of the t-test :
Are the mean ultimate tensile forces of wires different BEFORE and AFTER exposure ?

or 2. "ntd" no tensile data :
A sample was not collected, or the wire was too corroded to test.

Column F

1. IF column E = YES, then 4 entries:
AFTER mean (pounds), BEFORE mean (pounds),
coefficient of variation of BEFORE wire (%), and % change

or 2. IF column E = NO, then 4 entries:
AFTER mean, BEFORE mean,
coefficient of variation of BEFORE wire (%), and NCD = no change detected.
That is, coefficient of variation of BEFORE wire was larger than the apparent change in means. NCD may affirm the t-test result ("NO" entries).

Site 1 White Slough 01-HUM-101
post mile 70 northbound

Photo 4. Low tide on 29 Nov 1989 after installing 18” x 36” gabion test panels (box) on channel side slope. Panels tied to 5/16” nylon rope, tossed onto slope, rope tied to rebar.

Salt stains on culvert wingwall mark normal high tide elevation limit. Also note that vegetation is above high tide elevation.

Outgoing tide (ebb) is toward right,
incoming tide (flow) is toward left.

Photo 5. Before collecting test panels at low tide on 3 Dec 1992. Looking landward, a tidal gate (not visible) around channel bend at right, prevents saltwater from flooding pasture lands, while storm runoff can pass through gate into the slough. Tidal currents reverse direction twice daily, so for incoming tides, the far bank becomes the inside of channel bend. Just beyond panels, there is a relatively short length of dark area (arrow), and it is not shadows of vegetation, but shadows of cobbles and gravels, where very fine soil particles were removed by higher shear stress, typical on insides of bends. The other high shear stress zone is longer, and it is on the near bank along the outside of bend for incoming tides, evident by larger rocks protruding on bank.

Photo 6. After collecting panels at low tide on 3 Dec 1992, 2.85 years of exposure.
Panel prints on muddy side slope indicate about half or more of each panel was buried by an inch or two of naturally deposited fine-grained soil (bay mud). Upper parts of panels near top of slope were in direct contact with water, and corrosion compounds eroded by rising and falling water levels, relatively low velocities (5 fps and less), and wind-driven surface ripples. In the low shear stress zone, mud deposited and shielded most of each panel from erosion by tides, while corrosion continued. Also see photos 7 through 13 and captions. Cobbles and gravels pointed out in photo 5 are right of right-most panel print.

Test panels from Site 1 White Slough 01-HUM-101 post mile 70 northbound 3 Dec 1992
Bay mud was gently washed off.
Background is clean, washed concrete.

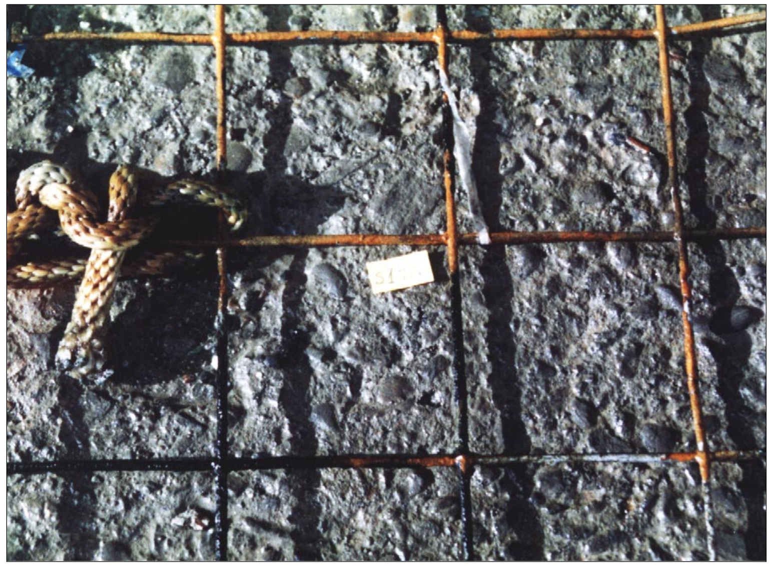


Photo 7. Product 1 (zinc-coated gabion mesh) after 2.85 years. Upper zone of test panels near top of slope. Product 2 was similar.

Steel bared (lower right) after loosely attached corrosion compounds were washed away, comparable to tops of panels not encased in mud, where natural erosion of corrosion compounds was by mild tidal currents, rising and falling water levels, and wind-driven surface ripples. Red rust and black corrosion compounds indicate, respectively, intermediate and advanced states of corrosion. 5/16" nylon rope at left, piece of paper towel stuck on 2nd vertical wire.

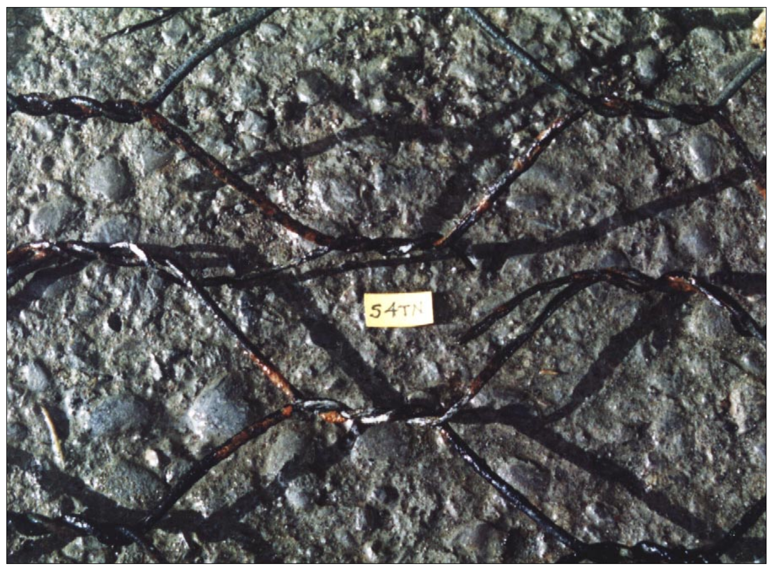


Photo 8. Product 4 (zinc-coated mesh) after 2.85 years. Upper zone of test panels near top of slope. Product 6 was similar.

Twisted wires had 42 percent of tensile breaks in twisted zone, due to corrosion, see photo 11 left wire pair. At this site, twists held saline-saturated soil, ideal for corrosion. These upper zone test panel wires were corroded and eroded by tides, and portions of some wires disintegrated.

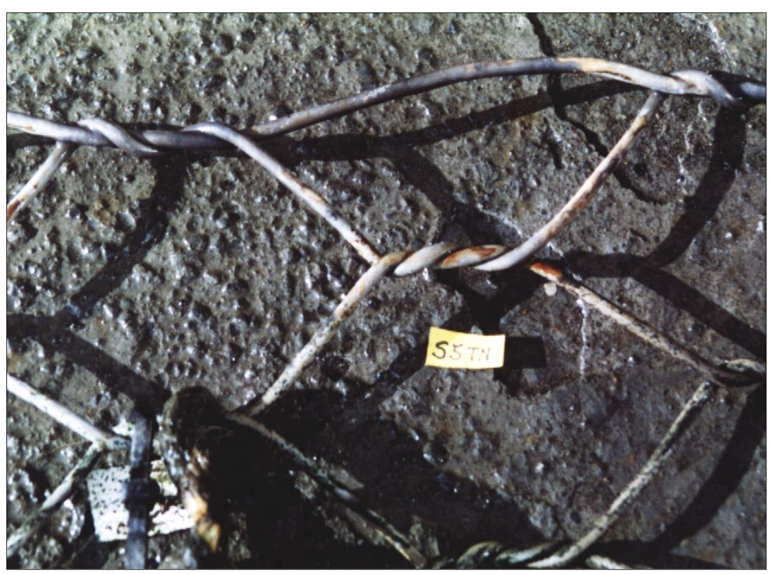


Photo 9. Product 5 (PVC-coated mesh) after 2.85 years. Upper zone of test panels near top of slope. Products 3 and 7 were similar.

PVC discolored from bay mud. Normal daily cycle of temperature change causes PVC to disbond from underlying wire (also seen and documented in lab study). At any cuts and breaks in PVC, electrolyte entered capillary space between wire and PVC, and corrosion proceeded. Corrosion compounds near cut ends of mesh were shielded by PVC and did not erode by tides like the zinc-coated wires.

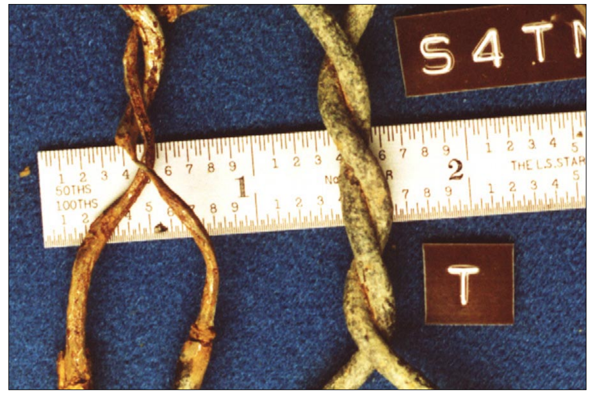
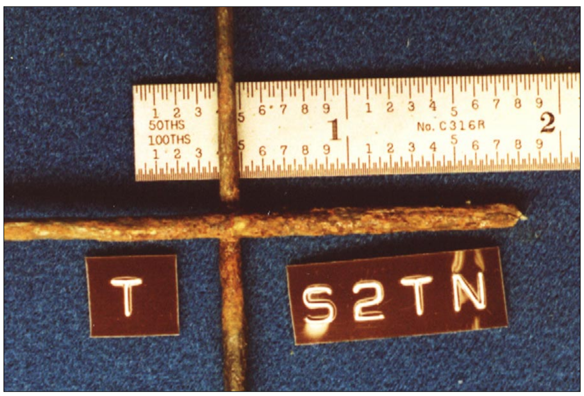


Photo 10 (top left image). Tidewater level changes, mild currents, and wind-driven surface ripples provided enough energy to erode tops of zinc-coated test panels that protruded above naturally-deposited bay mud.
Site 1 White Slough 01-Hum-101 post mile 70 3 Dec 1992

Photo 11 (top right image). Left wire pair of zinc-coated Product 4, twist very corroded and eroded by tides. Right wire pair corroded and shielded under 2” of bay mud and near initial diameter of 120 mils, after 2.85 years at Site 1. Product 6 was similar.



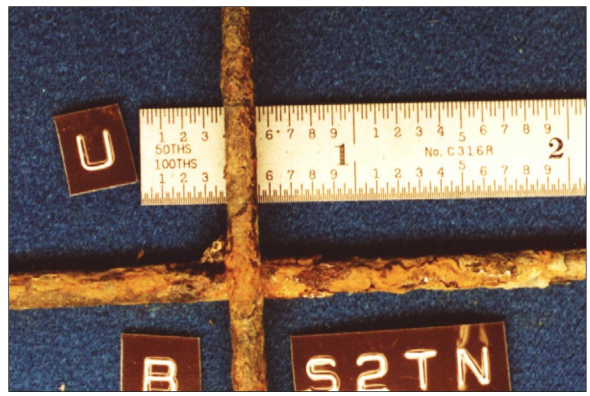
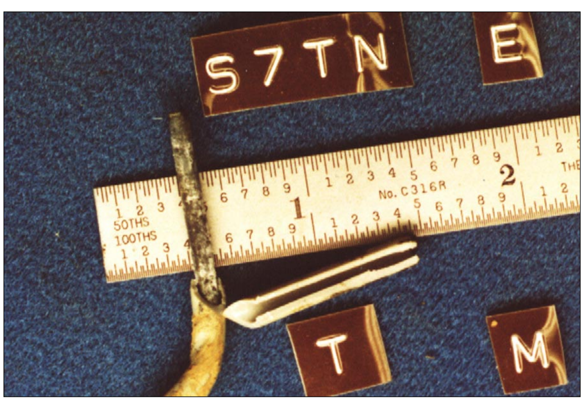


Photo 12 (middle left image). Product 2 zinc-coated welded wire corroded and eroded by tides. Initial diameter of 148 mils was less than 100 mils after 2.85 years at Site 1. Product 1 was similar.

Photo 13 (middle right image). Corroded wires of Product 2 shielded by bay mud, similar to right wire pair in photo 11, near (and larger than) initial diameter of 148 mils, after 2.85 years at Site 1. Product 1 was similar.



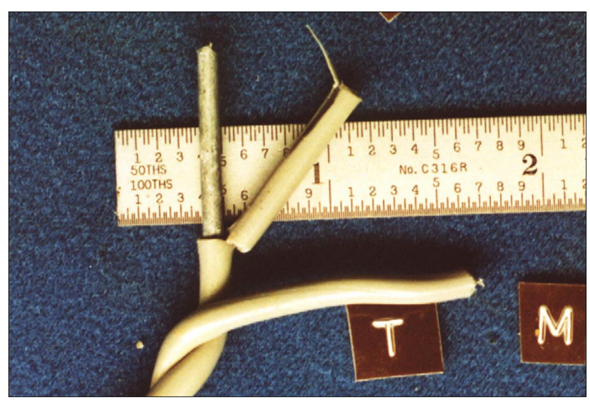


Photo 14 (bottom left image). Product 7 PVC disbonded from wire due to daily temperature changes, regardless of how PVC was bonded to wire. At cut edges of panels, electrolyte migrated into capillary space between PVC and wire. Site 1 after 2.85 years, white and gray corrosion compounds, early state of corrosion. Products 3 and 5 were similar.

Photo 15 (bottom right image). Product 7 Very little corrosion after 2.85 years at Site 1, PVC disbonded as in photo 14, however, this wire pair was about 8” from cut edge. Products 3 and 5 were similar.

Site 1 White Slough 01-HUM-101
post mile 70 southbound

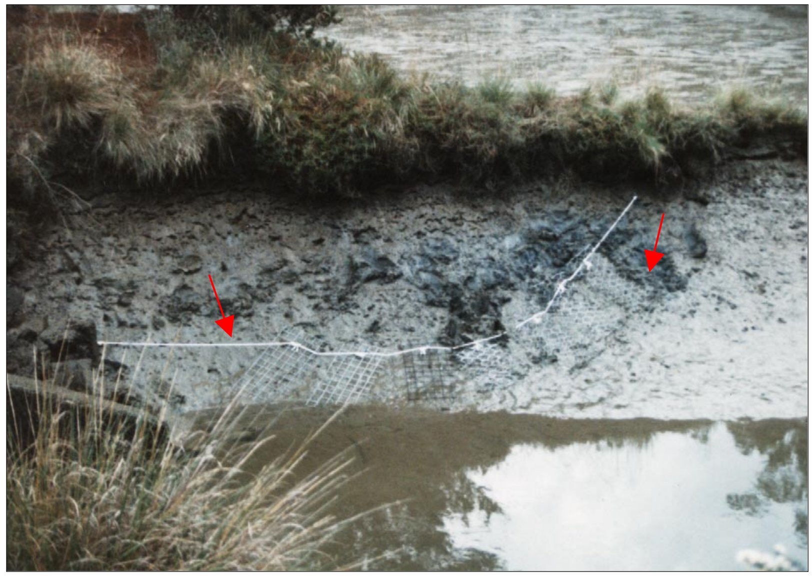


Photo 16. After installing 18” x 36” gabion test panels at low tide on 29 Nov 1989. Ebb tide drains toward right, ½ mile or more to Humboldt Bay. Panels tied to 5/16” nylon rope, tossed on channel slope in intertidal zone, ends of rope staked to channel slope with rebar. Panels of products 1 through 7, left to right, between arrows, mostly below rope.

Photo 17. Before collecting test panels at low tide on 24 May 1999.

Products 1 through 7 exposed for 9.48 years. More than ¾ of each panel was covered with 6 to 8 inches of bay mud.

Product 8 (arrow) exposed for 6.43 years, and about 2/3 of panel covered with bay mud.

Photo 18. Collecting test panels while standing on 1” x 6” boards to avoid sinking in bay mud.

Zinc-coated test panels were more than 50% disintegrated, even after very careful excavation, we were able to collect only portions of zinc-coated panels and the Al-coated panel, because of their advanced states of corrosion. 100% of PVC-coated test panels of product 3, 5, and 7 were collected. See photos 19 through 24.

Site 1 White Slough 01-HUM-101 post mile 70 southbound Test panels (except Al-coated) exposed for 9.48 years.

Photo 19 (top left image). Collecting a remnant of zinc-coated gabion test panel that did not disintegrate.

Photo 20 (top right image). Close-up of bay mud (light gray) and corrosion compounds (red, brown, and black) from disintegrated zinc-coated test panel, 5/16" nylon rope (arrow) muddy and saturated, otherwise OK.

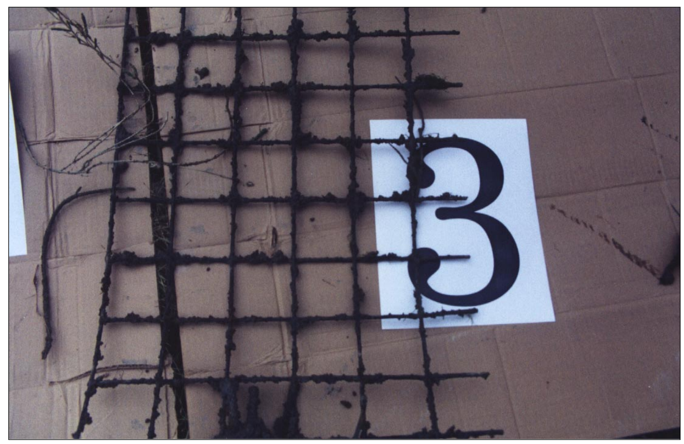
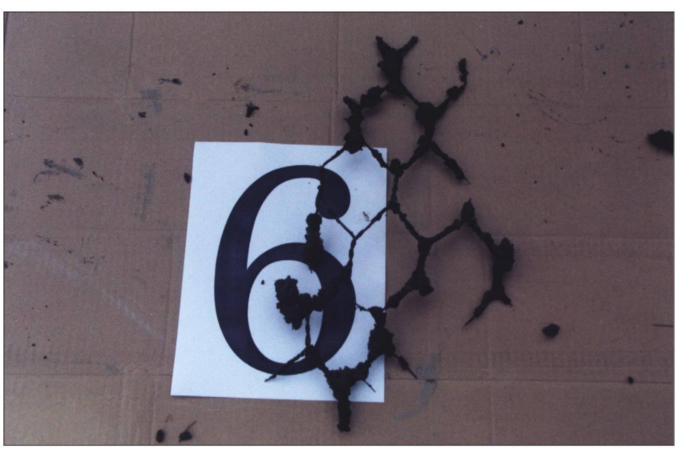


Photo 21 (middle left image) remnant of product 2, zinc-coated welded wire, product 1 similar.
Black numerals on white 8 ½ " x 11" paper.

Photo 22 (middle right image) product 3, PVC-coated wire OK, 100% intact, products 5 and 7 similar.



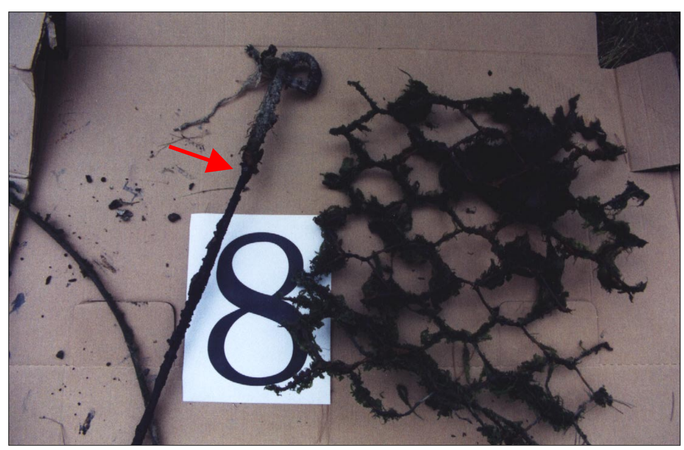


Photo 23 (bottom left image) remnant of product 6, zinc-coated twisted wire, product 4 similar.

Photo 24 (bottom right image) remnant of product 8, Al-coated twisted wire, about 2/3 of panel disintegrated in bay mud, after 6.43 years of exposure. 1/2 inch rebar stake (arrow) lost nearly half its diameter where exposed to tides near ground level in saturated bay mud (curved object is a stick).

Site 1 White Slough 01-HUM-101 post mile 70 southbound Control and corroded wires exposed 9.48 years (product 8, 6.43 years)

Photo 25. Product 1 welded 11-gage zinc-coated

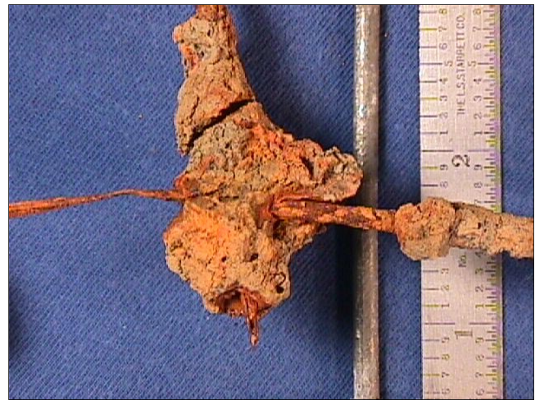


Photo 26. Product 2 welded 9-gage zinc-coated

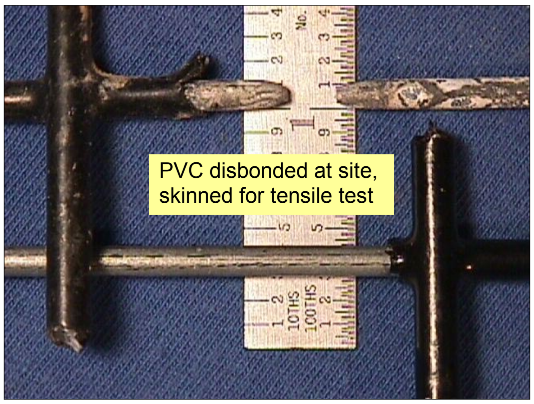


Photo 27. Product 3 welded 10.5-gage PVC-coated

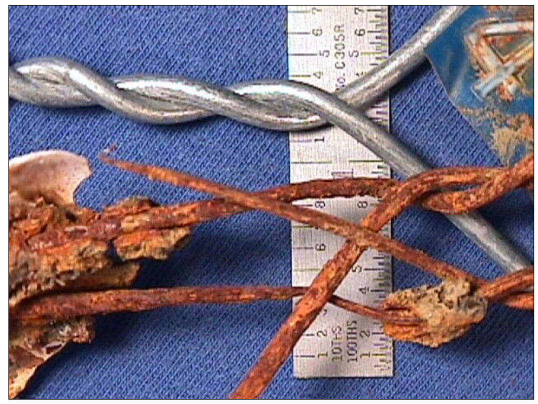


Photo 28. Product 4 twisted 11-gage zinc-coated

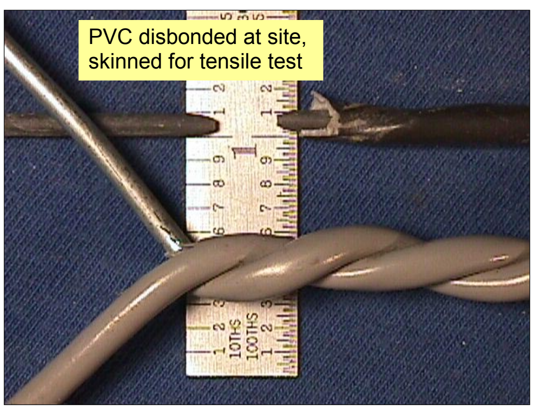


Photo 29. Product 5 twisted 12-gage PVC-coated

Photo 30. Product 6 twisted 11-gage zinc-coated

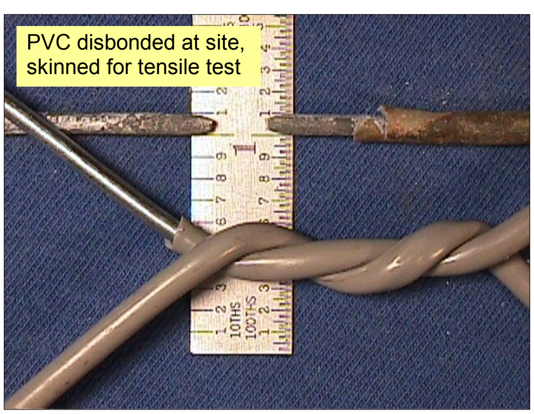


Photo 31. Product 7 twisted 12-gage PVC-coated

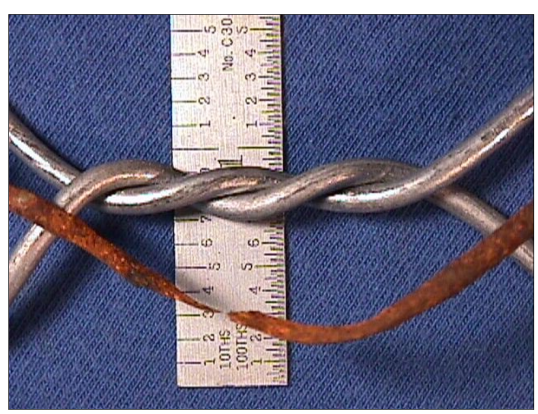


Photo 32. Product 8 twisted 11-gage Al-coated

SITE 2

The exposure of Site 2 is an inland freshwater stream, Prairie Creek, which flows year-round and has its source in Prairie Creek Redwoods State Park. The average annual rainfall as measured at Orick is about 67 inches. The creek is several miles inland from the Pacific Ocean, however it is not tidally influenced because of its elevation. Prairie Creek flows into Redwood Creek which then flows to the Pacific Ocean. Both creeks provide passage and habitat for steelhead, Coho salmon, and Chinook salmon (anadromous fish) and also for cutthroat trout (not anadromous fish). Because this region of northwestern California is often foggy, there was atmospheric corrosion, as seen by the dull gray (zinc carbonate) appearance of zinc-coated wires.

Site 2 is at the southerly end of the recently realigned 12-mile segment of State Route 101 known as the Redwood Park Bypass. A welded-wire gabion retaining wall made from product 1 was completed in 1988 to separate the creek and retain roadway embankment of (old) scenic highway 101 and the access ramp of realigned 101. The gabion wall intercepts and cuts-off a 500-foot meander of Prairie Creek. The wall is about 485-feet long and 15-feet high, made of five, 3-foot tiers of gabion baskets. In cross section, the bottom tier is 9-feet wide, that is, three, 3-foot wide cells extending from the creek into the embankment. Each subsequent tier is 1.5-feet less wide, such that the back of the wall has four, 1.5-foot wide steps, while the front of the wall facing the creek is smooth. The bottom tier was embedded 3-feet, so its top was at the 1988 creek bed elevation.

We attached 1 set of test panels to the face of the wall, about 1-foot higher than the creek bed. See Table 3A for exact installation dates and exposure times. The wall and test panels were not altered or disturbed by people in any way, from the day of installation to the day we collected all the test panels. After a few site inspections, by the middle of the 7th wet season (Feb 1996), the test panels were OK, and so was the wall (middle of its 8th wet season). There were no further inspections until May 1999, when we discovered a 50-foot failed section of wall, where creek flows continually impinge on the upstream end of the wall. The basic failure mechanism (details below) was corrosion and abrasion, also called corrasion. Bed materials in the Creek were not collected and lab-tested, however, we field-identified the particles as sub-angular fine sand to 3-inch rounded gravel (See Photo 36). We found no witnesses to the failure event, but, after reviewing our diaries and the hydrologic record at Orick, it was most likely the result of 9 seasons of continual corrosion, abrasion, and wire disintegration, along with large flows and swift currents resulting from the greater than 5-inch daily rainfall event of January 6, 1997. Statewide, there were several rain events that started after Christmas 1996, and extended through the first few weeks of January 1997. Collectively those events are called the January 1997 New Year's Storm, actually a series of warm tropical storms, which resulted in many damaged or destroyed roadways.

During our site inspections, we recorded a few non-storm, base flow rates and conductivity measurements of the creek. See Table 3C. Base flow rates were about 3 to 50 cfs, and conductivity indicated very little electrolyte. There is no stream gage on Prairie Creek, so there were no hydrographs to review. However, by measuring and estimating stream geometry, we estimated the peak runoff due to the January 6, 1997 event as 3500 cfs or greater. Photo 44 indicates that the peak flow depth was about 6-feet from the original creek bed at the wall, as seen by fern growth on the wall and nearby drift hanging on vegetation. For typical wet-season storm flows and velocities, the rust stain near the bottom of the wall indicated that ordinary high water was about 1-foot above the original creek bed. Flow depths in the creek approaching the wall were at least 2 feet, so the average approach velocity was about 4.6 fps. The creek and wall are skewed at about 30 degrees, so the impinging velocity vector at the wall has a magnitude of about (1.33 x 4.6) or 6 fps, at the threshold of moving fine sand particles. Based on the rainfall record at Orick, from November 1988 through December 1996 there were about 173 events 1-inch or greater, 78 events 1.5-inches or greater, and 27 events 2-inches or greater. During many of those events, there were likely flow surges that suspended and transported sand and sometimes gravel, thereby abrading corrosion compounds, especially on submerged wires, which were continually corroding. While the actual number and duration of abrasive flow events is not known, we know that as wires corroded, they also eroded and disintegrated. For about 100 feet from the impinging zone and downstream along the wall, the creek bed scoured and dropped at least 1-foot (See Photo 41). The greater than 5-inch rainfall of January 6, 1997 produced flows with sufficient energy to remove the rock-fill from bottom baskets. Rock-fill then dropped into the creek, and then it was transported by strong storm currents away from the base of the wall. With no bottom support, the wall rotated and literally fell on its face into the creek. See photos 33 through 49 and captions for details of the exposure, site history, and failure mechanism. After photographing and documenting the failed wall, all test panels were collected on 26 May 1999. District staff and other Caltrans units were immediately notified. The following excerpts are from an e-mail report by Racin, which describes the failure mechanism and recommends repair strategies.

Excerpts of 2 June 1999 e-mail :

The predominant failure mechanism of the gabion wall was ABRASION of the gabion wire mesh, over time, due to streambed materials being conveyed directly at the wall (30 degrees or so of impingement) and also paralleling the wall during storm runoff events. There is no bedload movement during normal low flow. With no confining wire, gabion rock-fill emptied from the lowest 9-foot wide tier, and also from the 4th tier down from the top of the wall. Apparently, when enough of the "unsupported beam" (lengthwise section of wall parallel to the creek) became unstable and unable to support the 3 uppermost tiers, the wall collapsed and rotated forward into the creek. Due to the cellular nature of gabion walls (3' x 3' x 3' cells), the entire wall did not fail, but tore apart from adjacent stable sections. Stable portions of the wall at either end of the failed zone remain in good alignment.

On 27 May 1999 ... I clipped a wire and spiral sample from the back of the failed wall, from the upstream base of the wall, and from the failed upper tiers of wall that were in tension. ... The research file photos show the condition of the stream and confirm the movement of bed materials.

While there is ongoing corrosion of the 11-gage wire at normal low water levels and lower, in areas of the wall that were NOT subjected to the abrasive action of bedload movement during storms, and where there is ACCRETION of streambed materials, there is still rusty looking wire that holds the gabion rock-fill in place.

Where there is no accretion of streambed materials, and especially immediately downstream of the 50-foot failed wall section, where there is SCOUR (about 3 to 4 feet from original bed elevation, streambed scoured to the BOTTOM-MOST gabion basket or just slightly lower), the wire has been "CONSUMED" by the moving, abrasive bedload. Several of the lowest gabion baskets have emptied and there are several more baskets in the 4th tier from the top of the wall that are empty. This zone of wall will be subjected to a similar failure at some near-future time (next winter ?).

Recognizing the importance of the stream as Coho salmon habitat, generic repair strategies were discussed ... and would require environmental clearance and permits. All (repair strategies) would likely require some sort of temporary dewatering of the creek in the repair zone. Temporary repair of the failed zone only may be considered, however, due to the sensitive nature of the creek and the possibility of losing a large mass of roadway fill (the on-ramp connecting the old highway that joins the new Redwood Bypass, southerly terminus), a long-term repair strategy is encouraged. Strategies are :

1. place rock riprap along the toe of wall along its entire length, 1/2 to 1 ton, to arrest the movement of stream bed materials (along the wall). Place concrete armor 3-feet above average streambed (elevation) and 3-feet below, grout any gabions with missing rock-fill.
2. place rock spurs upstream of the wall to TURN HIGH FLOW and direct it parallel to the wall.
3. design and drive sheet pile behind the existing wall (if feasible) and then remove the gabion wall.
4. drive H piles (on creek side of wall face) and form wooden headers to protect the wire from further abrasion. concrete (grout fill) the empty gabion baskets, concrete face of wall 3-feet below stream elevation to arrest corrosion of wire.
5. same as 4, but pour a concrete face, remove wooden headers. (consider concrete face to 3rd or 2nd tier from top of wall, because accretion may bring abrasive materials in contact with wire again.)

Any strategy will have to address the long-term corrosion of gabion wires. While my sporadic measurements of the water ... indicate a "not so hostile corrosive" environment, I would suggest that corrosion-resistant materials be used for repairs. ... Also, a long term repair strategy would have to address SCOUR at the base of the wall (historically about 3 to 4 feet). The original design of 3-feet below bed elevation did not appear to be deep enough, consider 5 feet minimum. The replacement of the entire wall with non-corrosive materials should be considered.

In March 2001, District 1 proposed a Minor A contract with repairs similar to strategies 1 and 2. Because recent winters were very mild with no high flow events, the 50-foot zone of slope at the failed wall did not appear to erode very much from creek flows. However, District 1 staff observed that elk were using the failed embankment scarp, as a path from the top of wall to the creek, and it is eroding.

Test panels did not indicate what happened to the failed section of wall, even though Product 1 test panels came from the same material lot as the wall. Unfortunately, test panels were placed about a foot too high to get the same severe, corrosive and abrasive exposure as the wall. Corrasion, (corrosion plus abrasion), is the underlying failure mechanism, and the wall would have failed with any of the gabion products.

Wires of all test panels were tensile and t-tested, and only products 3 and 7 showed any measurable strength loss. PVC was disbonded from wires due to daily temperature changes, and there was some corrosion near the cut ends of panels.

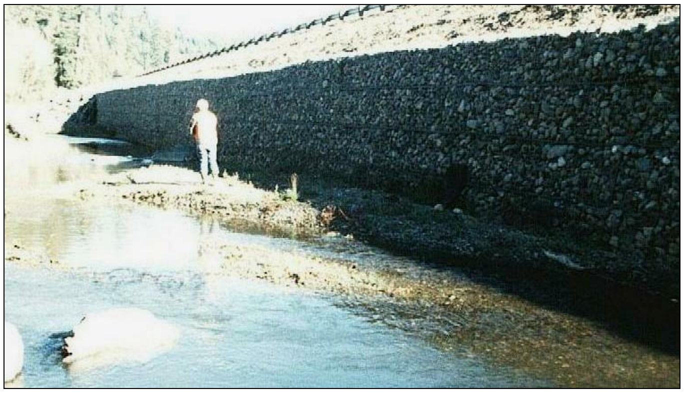
TABLE 3E-2. Prairie Creek Tensile and t-Test Results

A	B	C	D	E	F
2 Prairie Creek 01-HUM-101 125.9 Redwood Park near Orick northbound back of failed wall in creek	1	10.57	not mic'd	YES	806 863 5.63 -6.60 Wall inspected after 10.57 years. > 2 years estimated exposure in creek. YES is plausible, pits in submerged wires, unlike wall and test panels not submerged, maybe due to prior long-term moist soil contact behind wall (See Photo 47)
2 Prairie Creek 01-HUM-101 125.9 Redwood Park near Orick northbound test panels on vertical face of wall	1 2 3 4 5 6 7	9.49	116 118 120 144 141 146 126 129 131 116 113 116 101 104 104 116 116 118 101 100 101	NO NO YES NO NO NO YES	851 863 5.63 NCD 1450 1488 2.88 NCD 1109 1185 5.69 -6.41 822 816 6.12 NCD 601 621 5.02 NCD 785 792 3.70 NCD 601 638 5.61 -5.80 YES for PVC-coated wires is plausible, corrosion compounds were seen. capillary space between PVC and wire drew water at high creek stages. product 5 result says OK, but it looked like products 3 and 7. zinc-coated panels dried-out after high stages, so corrosion slowed

See page 30 for :
TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Regarding the test panel results, at first, the marginally close numerical values for products 3 and 7, which show losses of mean tensile force, does not seem reasonable. We expected "NCD", no change detected, for these PVC-coated products. Visual appearance was not noticeably different from control samples, as indicated in composite Photo 3, test wires in 1996, and also in 1999, when all the test panels were collected. The tabled comment in column F explains the YES results. So, why didn't zinc-coated test panels (and the rest of the gabion wall not submerged by creek flows) fair worse at this site ? Likely because zinc-coated products could air-dry after high creek stages, unlike PVC-coated samples which retained some water in the capillary space between the PVC and the wire.

Site 2   Prairie Creek   01-HUM-101 post mile 125.9



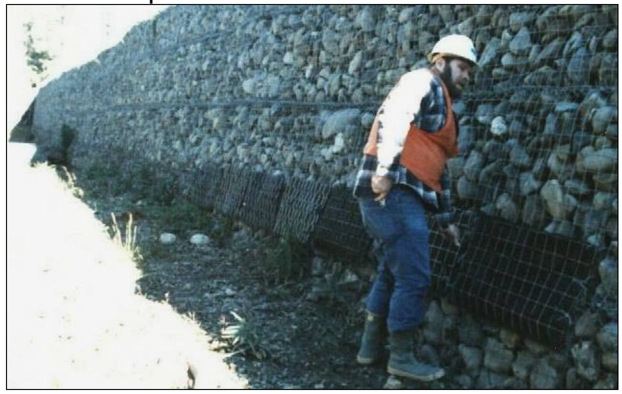


Photo 33 (left image). looking upstream toward upstream end of gabion wall (made of product 1), flow impinges from left, 30 degrees in plan view, 28 Nov 1989.

Photo 34 (right image). test panels fastened on 2nd tier of 5-tiered wall (1 tier is 3 feet high), next to aggraded zone opposite rock spurs in photo 33, 28 Nov 1989.

Photo 35. almost same view as photo 33, 9.5 years after installing test panels, 26 May 1999. 30” high scale (at right) on test panel of product 1 (8 ½” x 11” white labels). Upstream of 1-ton rock (circle), earth and geotextile are exposed (box), 50-foot section of wall failed by corrasion. Canvas bag on gravel bar.

Photo 36 (right image). Abrasive particles range from sub-angular fine sand to rounded 3-inch gravel.

Photo 37 (left image). looking upstream at reach of creek that impinges on wall, 14 Feb 1996. Alders (left side of image) bent nearly horizontal indicate recent high velocity event.

Photo 38 (right image). looking downstream at section of wall that failed about a year later, OK 14 Feb 1996. Camera rotated about 15 degrees to see wall in impinged zone. Drift on tree indicates recent high water stage. Round shadow (foreground) is 1-ton rock slope protection (riprap) at upstream end of wall.

Photo 39 (left image). wall at creek bed elevation, just upstream of wall, 14 Feb 1996. This zone protected by 1-ton riprap, not directly impinged-on by creek, rust on lower wires, white corrosion compounds on upper wires.

Photo 40 (right image) same location as photo 39, on 27 May 1999. stressed gabion (right) next to failed wall.

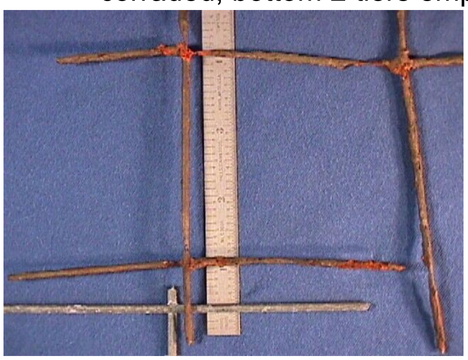
Photo 41. looking under 1 foot of water in scour zone, 50 feet downstream of failed wall, 15 feet upstream of test panels, 26 May 1999. Rusted wires corroded, some disintegrated (center, under water), rock-fill is no longer confined. Creek bed particle sizes range from fine sub-angular sand to 3-inch rounded gravel.

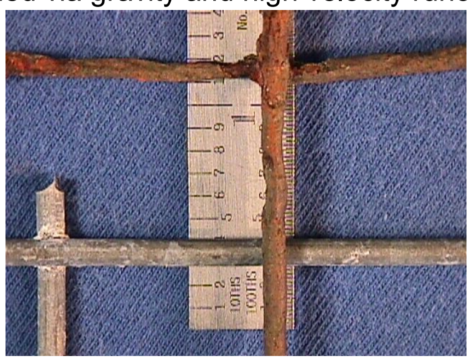
Photo 42. creek bed and wall under test panels, 26 May 1999. most bedload and high-velocity suspended sediment did not get here. Rust on low wires, no rust above ordinary high water, 1-foot above creek bed.

Site 2   Prairie Creek   01-HUM-101 post mile 125.9   26 MAY 1999

Photo 43 (left image). failed gabion wall in impinging zone of creek. Wires corraded and disintegrated, rock-fill emptied, then 50-foot section of wall collapsed during January 1997 storms. Riprap protected end of wall from abrasion, however, not from corrosion and possible future failure by continued corrosion. See Photo 49.

Photo 44 (right image). empty cells of baskets, downstream of 50-foot failed section of wall. After wires corraded, bottom 2 tiers emptied via gravity and high velocity runoff. Recent high water (arrow).





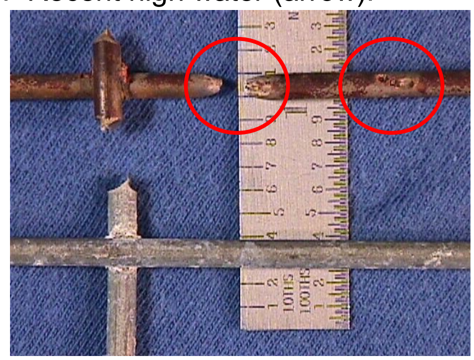


Photo 45 (middle left image). abraded corrosion compounds eroded by flowing water after 11 wet seasons.

Photo 46 (middle center image). close-up of clipped control wire and corraded wall wires.

Photo 47 (middle right image). control and tensile-tested wire from back of failed wall. Rust nodules randomly spaced on back-of-wall, submerged 2 years in Prairie Creek. After cleaning nodules, we saw pits (circled, at tensile break and nearby). Wires in Photos 45 and 46 corraded uniformly, more-or-less. Pits may be from soil grains pushed against wires, > 8 years of embankment soil pressure, moist soil contact, and 2 years in creek.

Photo 48 (left image). observer pointing out aggraded zone, about 200 feet downstream of collapsed 50-foot section of wall. About ¾ of wall along its length still had rock in bottom and 2nd tier of wall. 27 May 1999.

Photo 49 (right image). Close-up of aggraded zone in Photo 48, gravel bar temporarily protects corroded wire from abrasion below stage of ordinary high water (1-foot from creek bed) on 2nd tier of wall.
One missing wire segment, likely from construction abuse, see bent wires nearby. 27 May 1999.

SITE 3

The exposure of Site 3 is in the coastal foothills of northwestern California, about 1 mile from Site 2, but uphill and near the crest of a ridge which defines part of the watershed boundary of Prairie Creek. The average annual rainfall as measured at Orick is about 67 inches. Along the 12-mile segment of highway 101 known as the Redwood Park Bypass, there are miles of open channel drains, and they are made from zinc-coated gabions, product 4. The typical channel cross-section is trapezoidal, bottom width is 3-feet, depth is about 1.7-feet, and side slopes are 1.5H:1V. The gabion drains were built along tops-of-cuts and next to park boundaries to collect on-site and offsite runoff, dissipate it, and then convey it to nearby ravines, swales, and creeks. As at site 2, with prolonged fog, there was atmospheric corrosion of gabion wires.

While this site had about the same number of rainfall events as Site 2, there were no sustained flow events, because of the location in the watershed. As contrasted to submerged wires in Prairie Creek, we saw no rusty wires in the gabion open channels. We do not have precise counts of the number of flow events, so we simply state that runoff was intermittent. No base flow (non-storm runoff) was ever seen in gabion downdrains near post mile 127, and neither was ponded water ever seen in the gabion channels. Soil test results (Figure 3-1 and Table 3B) indicate that soil would probably not cause corrosion problems, although there are materials larger than fine sand to potentially cause abrasion, if runoff were to ever mobilize and transport the soil frequently. No failures were discovered near the test panels. The Caltrans maintenance foreman at Orick reported that occasionally, trees grew in the gabion downdrains. We suggested that trees be removed, if they obstructed flow into or out-of culverts, if damming of culverts could flood the traveled roadway, or if blocked flow could escape from gabion channels and cause erosion.

TABLE 3E-3. Redwood Park Bypass Tensile and t-Test Results

A	B	C	D	E	F
3 Redwood Park Bypass 01-HUM-101 127 southbound open channel downdrain	4	10.57	mic'd wires of channel, see note G.	ntd	No diameter reduction of buried wires. Facility OK, no failures, no distress seen 300 feet downhill or 500 feet uphill to through-cut slopes.
3 Redwood Park Bypass 01-HUM-101 127 southbound test panels on face of side slope open channel downdrain	1 2 3 4 5 6 7	9.49	116 117 120 144 145 150 126 126 130 116 114 118 101 104 106 116 117 118 101 99 101	NO NO NO NO NO NO NO	842 863 5.63 NCD 1492 1488 2.88 NCD 1158 1185 5.69 NCD 814 816 6.12 NCD 635 621 5.02 NCD 803 792 3.70 NCD 644 638 5.61 NCD

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Note G. Two wire diameters (in mils) were measured 90-degrees apart on 6 different wires :

Sun	118, 120	121, 116	118, 119	117,119	118, 119	119, 117
Shade	119, 118	118,117	116, 117	116, 117	118, 117	118, 118

By inspection, there is no measurable difference between wire diameters in the sun versus wires in the shade.

The tensile and t-test results do not appear to be unusual. Atmospheric corrosion (graying of wires by the formation of zinc carbonate) occurred. There was no noticeable, hydraulically induced abrasion, to either test panels or the open channel gabion downdrains.

See photos 50 through 58 and captions for details of the exposure at site 3.

Photo 50. seven test panels fastened to north-facing side of gabion open channel downdrain (made of product 4), looking uphill, 28 Nov 1989. Compare to photos 51 and 52.

Photo 51. test panel of product 8 (Al-coated) fastened to channel on 24 Jan 1992, about 3 years after products 1 through 7

Photo 52. Site and test panels OK after 11 wet seasons, before collecting wire samples, 26 May 1999.

Remainder of panels left in place.
8 ½" x11" white labels indicate products.

Site 3   Redwood Park Bypass   01-HUM-101 post mile 127

Photo 53. after installing product 8 test panel, looking downhill, 24 Jan 1992. Compare to photo 54.

Photo 54. downdrain OK after 11 wet seasons, 26 May 1999.
Sign (left center background) indicates “Prairie Creek Redwood State Park - Next Exit”.

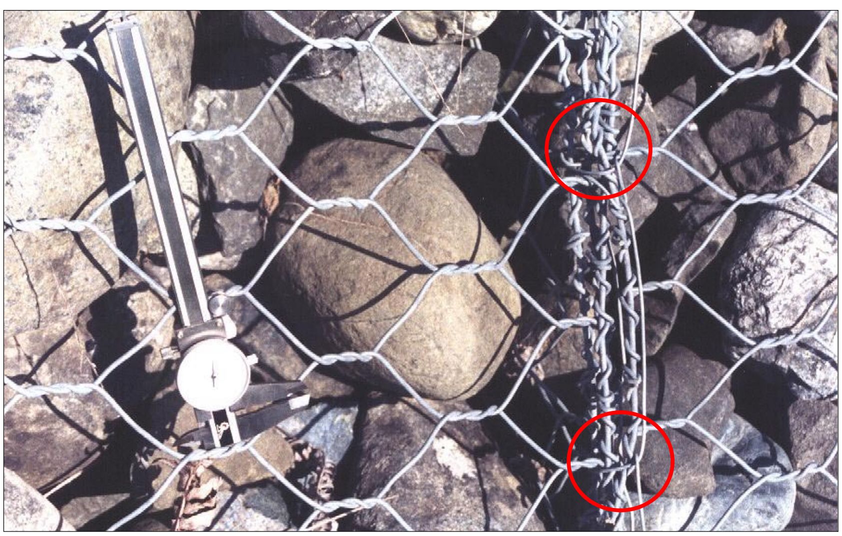


Photo 55. At this and other sites, we measured wire diameters of full-scale gabion facilities and inspected job quality. Several joints were partly “out-of-spec”. Caltrans requires alternating single and double half-hitches at 4-inch nominal spacing, circled ties are single half hitches at 6-inch nominal spacing. A feature “within spec” is that all wires of the joint were enclosed by standard tie wire in a single pass. 26 May 1999

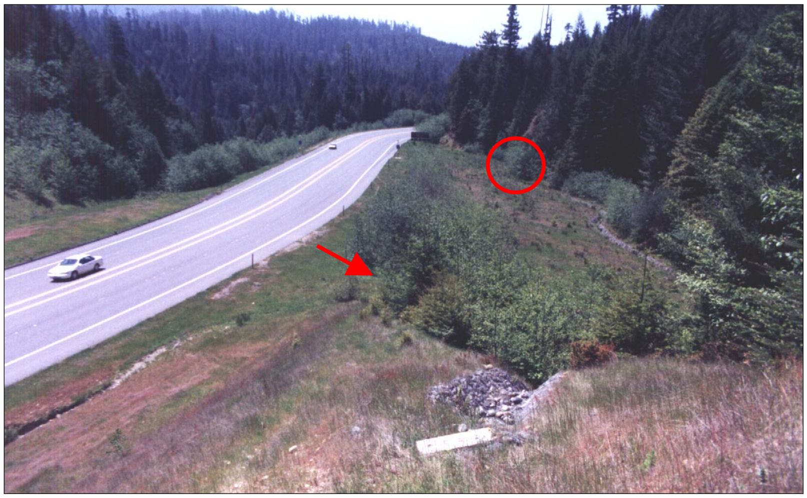


Photo 56. Overlooking part of 10-acre drainage area from top-of-cut. Beginning of gabion downdrain in foreground by 30" white scale. Runoff flows past test panels (circle). Road shoulder gully from slope and shoulder runoff (at left, 10' past toe of slope) connects to gabion channel behind trees (arrow).

Photo 57. Where 18" deep gully from slope and shoulder runoff connects to gabion channel (at left). Top 1-foot of 30" white scale in gully is visible. Super-elevated road drains away from gully toward right.

Photo 58. Looking uphill at gabion downdrain and confluence (hard hat for scale) with gabion channel (flow is to left) that gets runoff from road shoulder gully. OK after 11 wet seasons.

SITE 4

The exposure at Site 4 is a plateau of meadows and marshes in the Sierra Nevada, Mohawk Valley, which is at about elevation 4400 feet above sea level, near the town of Clio in northeastern California. The nearest recording gage is at Portola, where the average annual rainfall is about 23 inches. The Portola gage may not represent the amount of precipitation and snow that produces runoff in Mohawk Creek. There is a full-scale gabion facility made from product 4 mattresses about 500 feet long, that functions as road slope protection along Route 89. It consists of 1-foot high gabions with counterforts along the toe and at regular intervals up-and-down the slope. The roadbed elevation was raised to avoid flooding from high stages in the nearby Middle Fork of the Feather River, and to guard against road washouts during rapid snowmelt. A double 10'-11" wide x 7'-1" high, structural steel plate arch culvert conveys Mohawk Creek under Route 89. The creek has cobble and gravel invert armor that was apparently mobilized once during our observations, in January 1997. The water is usually crystal clear and cold. A 36-inch culvert about 500-feet from Mohawk Creek, conveys snowmelt when there are large accumulations of snow in the upstream marshes and meadows. The gabion-protected road slope connects to Mohawk Creek 500-feet away along the toe of slope, and serves as an overflow channel during high stage runoff. We placed 1 set of test panels on the mattresses in the overflow zone, in a mostly sunny location that had predominantly air exposure, except in winter, when the site was covered with snow or when it rained. Soil test results are in Table 3B and Figure 3-2, and they indicate that corrosion would likely not be a problem. As seen by the tensile and t-test results in Table 3E-4, for most of the gabion facility and the test panels, corrosion was not a problem, except for the inlet invert apron of the 36-inch culvert. The apron was made of gabion mattresses and was likely submerged for prolonged times in stagnant water (ponded), which led to accelerated corrosion. Table 3D indicates that stagnant water had very low dissolved oxygen, conductivity not very different from the clear flowing water of Mohawk Creek, and virtually no salinity. Comments (3rd row of column F) help explain the relatively good performance of wires in Mohawk Creek, sometimes submerged. Some concrete got on the mesh, when the 3-foot deep counterforts were concreted during initial construction. It is likely that the creek experienced some dry periods, which helps explain the relatively good condition and performance of wires. The first two rows of Table 3E-4 show results that are not especially unusual for the test panel wires, which were exposed to mostly air. See photos 59 through 66 and captions for details of local exposures at site 4.

Table 3E-4. Mohawk Valley Overflow, Invert, and Mohawk Creek Tensile and t-Test Results

A	B	C	D	E	F
4 overflow zone 02-PLU-89 5.2 Mohawk Valley near Clio test panels on mattress lids at toe of slope	1 2 3 4 5 6 7	8.97	116 116 120 144 145 148 126 127 130 116 115 116 101 104 105 116 116 118 101 100 102	NO NO NO NO NO NO NO	872 863 5.63 NCD 1501 1488 2.88 NCD 1189 1185 5.69 NCD 800 816 6.12 NCD 612 621 5.02 NCD 783 792 3.70 NCD 659 638 5.61 NCD
4 culvert inlet invert apron 02-PLU-89 5.2 Mohawk Valley near Clio invert apron mattress	4	9.15	not mic'd	YES	427 816 6.12 -47.7 based on measurements of stagnant water in Table 3D, YES is plausible. 50 percent diameter loss estimated, due to corrosion.
4 Mohawk Creek 02-PLU-89 5.3 Mohawk Valley near Clio slope protection along toe and submerged by creek	4	9.91	not mic'd	ntd	cobbles likely transported in Jan 1997, some sediment may be transported during high flows. About 50 feet from creek, 1-foot below surface, wire is OK, no diameter reduction, no rust, zinc coating still present. mattress submerged in creek OK, maybe influenced by concreted counterforts. no abrasion.

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Site 4 Mohawk Valley Near Clio 02-PLU-89 post mile 5.2

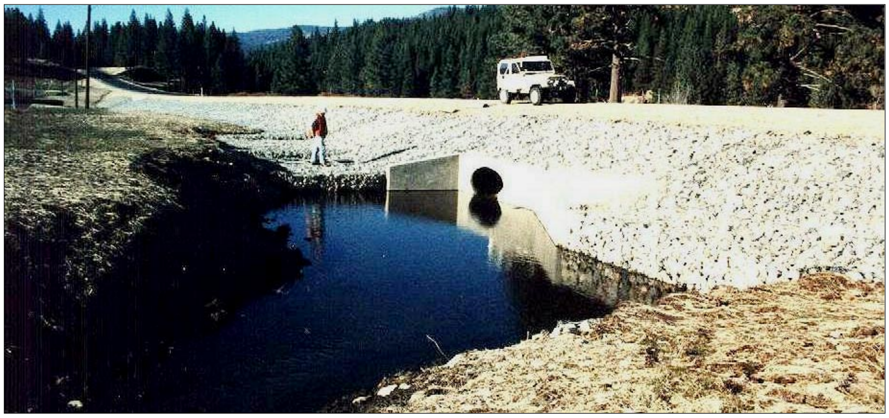


Photo 59. Observer at culvert overflow zone, test panels attached to gabion mattress lids at toe of slope, 2 Nov 1989. Road washed-out frequently before it was elevated. Slopes protected with gabion mattresses. Submerged culvert inlet invert apron also lined with mattresses. Water from rain, snowmelt, springs.

Photo 60. Test panels fastened to mattress lids in overflow zone. OK after 9 wet seasons. Before collecting wire samples from 18-inch x 36-inch test panels, 20 Oct 1998.

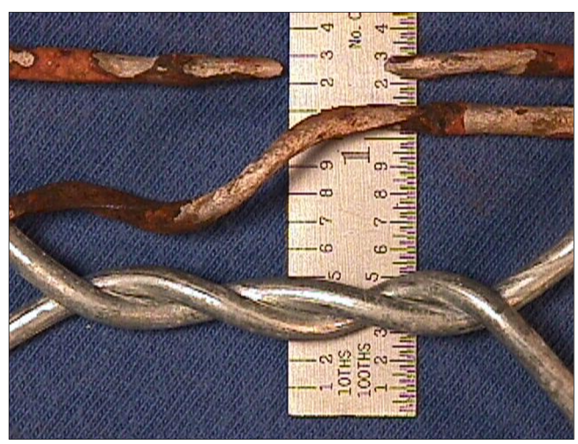


Photo 61 (left image). After collecting wire samples from 8 products, remainder of panels were left in place, 20 Oct 1998. Water ponded 1-foot or higher, as indicted by stain on 36-inch culvert wingwall (line). Mattress of inlet invert apron submerged in stagnant water, > 50 percent silted-in, almost completely covered with vegetation. Water measurements showed low dissolved oxygen, prolonged stagnant water. Sag in road (at left, about 500 feet away) is where Mohawk Creek is conveyed under road. See photos 63 and 64.

Photo 62 (right image). Top wire from invert tensile-tested, lost about 50 percent strength and diameter after 9 wet seasons, 20 Oct 1998. Middle wire (other wire of twisted pair) shows diameter loss in the twisted zone, bright areas are bare, corroded steel wire. Shiny control wire pair (bottom) BEFORE exposure for contrast.

Photo 63.
Inlet of double 10'-11" wide x 7'-1" high structural steel plate arch culverts which convey Mohawk Creek under route 89. Flow is continual in normal water-years. Culverts and gabion mattress slope protection, 1½ years after construction, 6 Feb 1991. At toes of slopes, gabion counterforts (3' x 3' cross section) were concreted during construction. Toe at creek has 27-foot plan view radius (left, far side) and 40-foot radius (right, near side). Counterforts built 3-feet below culvert invert elevation for possible local scour.

Photo 64. Gabions, culverts, and Mohawk Creek after 10 wet seasons, 20 Oct 1998. Natural stream materials line inverts of both culvert barrels, as contrasted to photo 63. Above normal runoff in January 1997 transported creek bed cobbles and gravel, left side aggraded more than right side. Thalweg shifted to right culvert barrel.

Photo 65 (left image). Gabion-protected slope on right side of culvert inlet, 20 Oct 1998. Sparse vegetation in baskets indicates prior high water, about 4-feet from toe along slope line (6-foot long rod, arrow).

Photo 66 (right image). Submerged wires below end of 6-foot long rod and wires in nearby moist soil at toe of slope (not in image) had no rust after 10 wet seasons, still had zinc coating, 20 Oct 1998. Rod at air and water interface of gabions. Wires OK on both sides of creek. Creek may have been diverted for livestock and irrigation, thus gabions may not have been submerged continually. Soil may have dried out in dry water-years, that is, when annual precipitation amount was less than long-term average value.

SITE 5

Site 5 is about 1/2-mile from Site 4, and the exposure of Site 5 is a wetland (marsh), in Mohawk Valley, which is at about elevation 4400 feet above sea level, near the town Clio in northeastern California. The nearest recording gage is at Portola, and the average annual rainfall there is about 23 inches. The Portola gage may not represent the amount of precipitation and hence the source of runoff to the wetland, snow and rain from mountains and the valley. A gabion energy dissipater was built at the outlet of a double-barreled, bituminous-coated, corrugated steel pipe, 60-inches in diameter. The energy dissipater is submerged in stagnant water most of time. It consists of three 12-foot long gabions, side-by-side, laid perpendicular to the culvert flow lines. The middle basket is depressed about 6-inches below the upstream and downstream baskets. We placed 1 set of test panels on the depressed, middle basket of the energy dissipater, such that they were always submerged. In winter, the site was sometimes iced over and covered with snow. There were very low velocities as evidenced by the absence of a scour hole. Soil was sampled at the inlet and the outlet of the culvert. Soil test results are in Table 3B and Figure 3-2, and they indicate that corrosion would likely not be a problem. However, as seen by the tensile and t-test results in Table 3E-5, the energy dissipater made of zinc-coated product 4 and other zinc-coated products showed advanced states of corrosion, similar to the gabion wires at Site 4 of the inlet invert apron. The 20 parts per million of sulfate ion hinted at the likelihood of sulfur fixing bacteria. We later deduced the present of sulfur fixing bacteria by the foul odor that arose from stagnant water, when we collected the test panels almost 10 years later. Table 3D indicates that stagnant water had very low dissolved oxygen, conductivity not very different from the clear flowing water of Mohawk Creek, and virtually no salinity. It appears that stagnant ponded water accelerated corrosion of zinc-coated products, and even one of the PVC-coated products showed the beginning of strength loss. The mechanism has been seen at other sites : after cyclic temperature changes, the PVC coating disbonds from the metal, leaving a capillary space. Electrolyte then migrates into the capillary space and corrosion occurs.

In Table 3E-5, the results for zinc-coated wires do not seem unusual. A tactile test (we felt wires under water) of the energy dissipater was comparable to product 4 test panel wires, and they both had about half the diameters of the control wires. For products 5 and 7, recall that NCD means no change detected, and this seems reasonable. All PVC-coated products showed evidence of electrolyte migration into the capillary space between the PVC and the wire, so the measurable loss of tensile force for product 3 seems plausible, but not quite in-line with products 5 and 7. Perhaps the small data-set that established the coefficient of variation (for all products) was too small to describe their true variability. See photos 67 through 75 and captions for details of local exposure at Site 5. The 1-mile segment of Route 89 that includes sites 4 and 5 won the first "TRANNY AWARD" for the Highway Project category, as determined by the California Transportation Foundation in April 1990.

TABLE 3E-5. Mohawk Valley Energy Dissipater in Wetland Tensile and t-Test Results

A	B	C	D	E	F
5 energy dissipater 02-PLU-89 4.7 Mohawk Valley near Clio test panels on dissipater always submerged	1 2 3 4 5 6 7	9.79	not mic'd not mic'd 126 130 131 not mic'd 101 103 104 not mic'd 101 100 102	YES YES YES YES NO YES NO	668 863 5.63 -22.6 1074 1488 2.88 -27.8 1101 1185 5.69 -7.09 377 816 6.12 -53.8 616 621 5.02 NCD 305 792 3.70 -61.5 646 638 5.61 NCD
5 energy dissipater 02-PLU-89 4.7 Mohawk Valley near Clio dissipater always sumerged	4	9.91	not mic'd	ntd	stagnant water most of time very low velocity, no scour hole at outlet

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Site 5   Mohawk Valley Near Clio   02-PLU-89   post mile 4.7

Photo 67. Author fastening test panels to gabion energy dissipater, 2 Nov 1989.
Dissipater made from product 4, at outlet of double 60-inch diameter bituminous-coated culverts.
Palustrine emergent persistent wetland constructed and planted by contract. Contrast with photo 71.

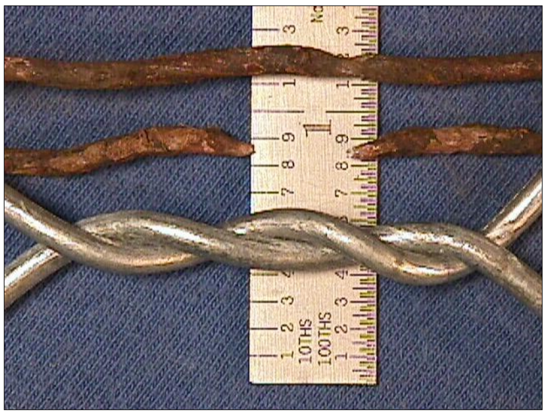
Photo 68. After attaching test panels to energy dissipater, 2 Nov 1989. By 1993 test panels became always submerged. Culvert outlet apron at same elevation as test panels. Contrast with photo 71.

Photo 69 (left image). Snow-covered energy dissipater in wetland, 2 Dec 1992.
Wetland plants (Carex nebraskensis, Nebraska sedge) fairy well-established after about 3 seasons.

Photo 70 (right image). Fastening product 8 test panel to dissipater near culvert outlet, 3 years after products 1 through 7 were placed, 2 Dec 1992. Rust stain (arrow) on flared end section at right, indicates normal high water. As snow melts in late spring, water level rises, submerging all of dissipater.

Site 5 Mohawk Valley Near Clio 02-PLU-89 post mile 4.7

Photo 71. Dissipater and panels under 9-inches of foul smelling (sulfur-like) stagnant water and muck (fine flocculate). Difficult to find test panels among mature Nebraska sedge (Carex nebraskensis) 17 Aug 1999. Contrast with photos 67 and 68. Found test panels by feeling for them in muck, clipped samples of 8 products, remainder of panels left in place. Dissipater and zinc-coated test panel wires lost about half their diameter.



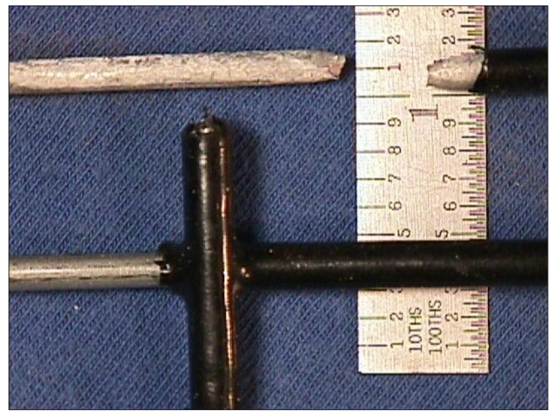
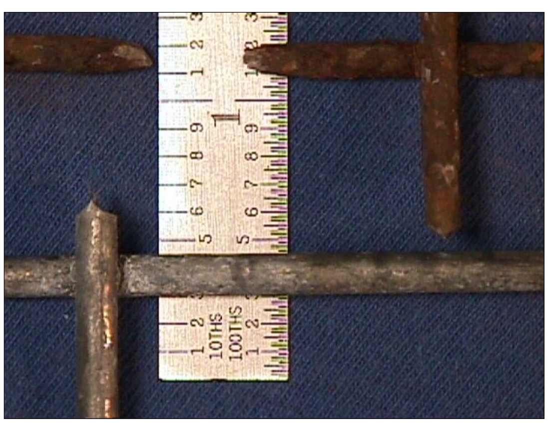


Photo 72 (left image). 2 upper wires are product 4 test panel wires (dissipater made from product 4), typical of zinc-coated wires submerged about 10 years, contrast to (bottom) control wire pair. Middle wire tensile-tested, broke in twisted zone. Top wire is other half of twisted pair, lost cross-sectional area in twisted zone due to corrosion. Product 6 similar. Energy dissipater wires felt very similar to products 4 and 6.

Photo 73 (right image). Top wire is product 3 test panel wire, typical of PVC-coated wires submerged about 10 years (bottom) control wire, skinned for contrast. Top wire tensile-tested, necked-down section indicates OK test. White corrosion compounds on top left skinned wire, because PVC disbonded from underlying metal, as a result of exposure to changes in daily and seasonal temperatures, same disbonding on products 5 and 7. After disbonding, water with electrolyte migrated into and along capillary space, and corrosion occurred.



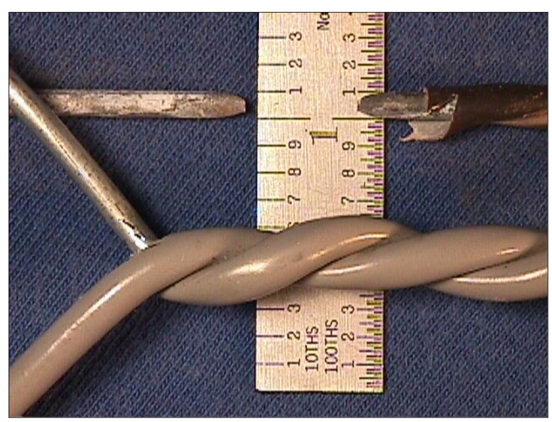


Photo 74 (left image). Product 2 test panel wire (top) after 10 wet seasons, tensile-tested, (bottom) control wire. Product 1 similar.

Photo 75 (right image). Product 5 test panel wire (top) after 10 wet seasons, tensile-tested, (bottom) control wire. Product 7 similar.

SITE 6

The exposure at Site 6 is along US 50 in the Sierra Nevada at elevation 7000 feet above sea level, near Echo Summit, in eastern-central California. The nearest rain gage is at Echo Summit, and the average annual precipitation measured as rainfall is about 52 inches, however, most of the precipitation is snow. A gabion wall was built from product 1 to retain the road shoulder embankment of a passing lane in steep terrain. The wall consists of 1 tier and sometimes 2 tiers of 6-foot long gabion baskets (3-foot high x 3-foot wide cross-section). The 6-foot dimension projects toward the center of the road. We did not collect a soil sample for lab testing, however, the soil was field-identified as decomposed granite, and particle sizes range from fine to coarse sand. Decomposed granite drains very freely, so the exposure time of buried wires to dissolved road salts during snowmelt is relatively brief. We fastened 2 sets of test panels to the face of the wall, a south aspect, that is, facing the sun. In winter, when the road and shoulder were blanketed with snow, about half or less of the wall face was covered with snow, because the wall is perched at the top of a ravine with a very steep slope. Zinc-coated test panels showed the characteristic dull gray appearance (zinc carbonate) of atmospheric corrosion, and so did face panels of the wall. Wires of gabion lid panels under geotextile were rusted, indicating that zinc was “consumed" by the corrosion process, however, the wall was performing well.

For wires of test panels of all products, the tensile and t-test results in Table 3E-6 indicate NCD, no change detected, and this is reasonable. However, wires of the lid panel appear to have gained strength. The test panel results are not unusual, but the apparent gain of strength of rusted lid wires seems unusual. Diameters of lid wires were “within specs” at 120 to 121 mils, while diameters of test panel wires ranged from 112 to 115 mils, a few mils below the required minimum of 116 mils. So, larger diameters is part of the reason for the apparent greater strength of lid wires. The phenomenon of strain aging is also very likely. If we momentarily ignore the coefficient of variation criteria for detecting any changes, and if we assume that the AFTER mean tensile forces of test panel wires were from a large sample, then there appears to be a trend of increased wire strength for all products, except product 6. However, the apparent gains of strength of test panel wires were much smaller than the 28.3 percent strength gain of lid wires. Another factor for the large strength gain of lid wires is the steel mixture may have been a “better” formulation than the steel of test panels. There is also the likelihood that the data-set for establishing the coefficient of variation was too small to describe the variability of product 1 test panels and other products. See also pages 16 and 17 for similar explanations of the phenomenon of steel gaining strength. While PVC disbonded from the underlying wires, because of the good drainage in decomposed granitic soil, there was little opportunity for electrolyte (chloride ion in runoff) to migrate into the capillary space between the PVC and the wire, as we saw at other sites where test panels were submerged. See photos 78 through 82 and captions for details of local exposures at Site 6.

TABLE 3E-6. Little Norway Tensile and t-Test Results

A	B	C	D	E	F
6 Little Norway 03-ED-50 63.9 eastbound passing lane elev. 7000 feet wall lid panel	1	11.18	116 120 121	YES	1107 863 5.63 +28.3 Lid panel wires mostly rust covered with some white residue, likely zinc chloride (chloride ion from deicing salts in roadway runoff). Wires on face of wall OK
6 Little Norway 03-ED-50 63.9 eastbound passing lane elev. 7000 feet test panels on vertical face of wall	1 2 3 4 5 6 7	9.74	116 112 115 144 144 147 126 127 129 116 113 117 101 104 105 116 116 118 101 100 102	NO NO NO NO NO NO NO	864 863 5.63 NCD 1503 1488 2.88 NCD 1191 1185 5.69 NCD 834 816 6.12 NCD 633 621 5.02 NCD 785 792 3.70 NCD 657 638 5.61 NCD

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Site 6 Little Norway 03-ED-50 post mile 63.9

Photo 76. Gabion wall made from product 1 after 1 year, 21 Nov 1990.
Test panels had mostly air exposure, except in winter they were partially covered with snow.
This image is after 1st snow near start of 2nd wet season. Snowmelt had roadway deicing salt.

Photo 77. Wall and test panels exposed to shade, direct sun, rain, and snow. Observer above 2nd set of test panels (circle), back-up if 1st set (beyond arrow) was lost. Passing lane stable after 11 years, 4 Aug 1999.

Photo 78. Wall OK after 11 wet seasons, test panels OK after 10 wet seasons.
Wire samples collected from 8 products, remainder of panels left in place, 4 Aug 1999.

Site 6   Little Norway   03-ED-50   post mile 63.9


Photo 79 (left image). Collected sample of lid panel (product 1), 4 Aug 1999. Removed soil, lifted nonwoven RSP-fabric, cut-out 18" x 6" sample (in hand), repaired cut-out with product 3 (black PVC-coated mesh).

Photo 80 (right image). Special pliers used to close interlocking fasteners (stainless steel), 4 Aug 1999. After 11 years nonwoven geotextile was not blinded, some fines migrated through.

Photo 81. Replaced RSP-fabric then restored slope, 4 Aug 1999.

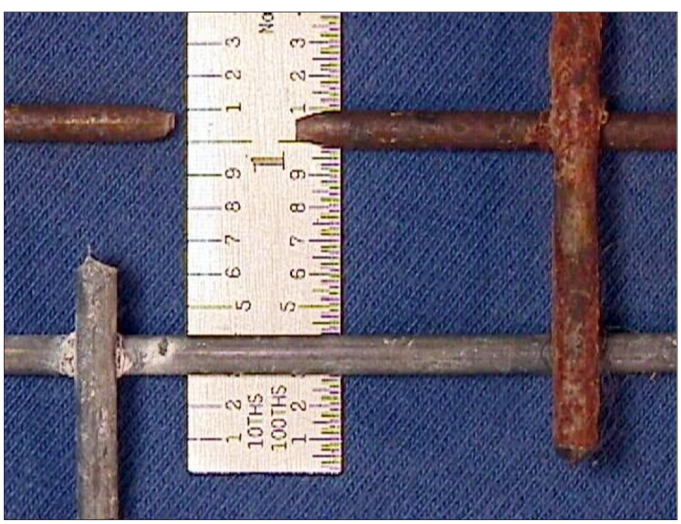


Photo 82. Top wire tensile-tested, from lid panel, contrasted to control wire (bottom). Large (28 percent) strength gain, likely due to larger diameter lid wires, strain aging, relatively small sample (n = 38 wires) to calculate coefficient of variation, and different heat (batch) of steel.

SITE 7

The exposure of site 7 is along the shore of the Pacific Ocean in Monterey County. The average annual rainfall as measured at Willow Springs is about 27 inches. This part of the California coast is often foggy, and storm waves can sometimes reach above 25 feet, as reported by one observer. As reported in [Racin, reference 5], there are four full-scale gabion facilities of product 5 that were completed in 1985. There are two rock slope protection (RSP, also called riprap) revetments to protect the toes of roadway slopes from wave erosion. The prominent rock formation in photos 84, 86, 87, and 98 is locally called Shale Point, so we called the revetment north of Shale Point "north RSP", and we called the revetment south of Shale Point, "south RSP". The 720-foot long south RSP is a deepwater location, where waves break directly on the revetment. The 600-foot long north RSP is a shoal water location, where waves break on the beach during low tide, and on the revetment during high tide. Both revetment cross sections are sloped at 1.5H:1V and consist of a geotextile, a 1-foot high PVC-coated gabion mattress, and an 8-foot thick layer of 8-ton rock. The 1-foot high mattresses were substituted for a California Bank and Shore "standard" three inner layer design of RSP, to reduce the total thickness by 7 feet (normal to finished slope). The two gabion retaining walls buttress the toes of previously over-steepened slopes that were naturally eroded by wave action. The finished slopes above the walls are 1.5H:1V. The south wall is about 400 feet long and the north wall is about 550 feet long. Each wall is 7 tiers high, with the first 2 tiers below ground as shear keys. The buried bottoms of each wall are at about 4-feet above sea level, and both walls are protected by rocky beaches from normal daily high tides and waves, so they only get direct wave attack during storms with above-normal high tides and waves. The wall faces are stepped 3-feet wide in cross section. As reported in [Hoover, reference 4], test panels of product 4 (zinc-coated mesh) and product 5 (PVC-coated mesh) were attached to the walls at various elevations in 1986. No test panels were attached to the gabion mattresses under the 8-ton RSP, and no additional test panels of other products were attached to the walls.

Both the south and north sea walls and the roadway slopes are OK, even though many wires are broken on the treads of the step-faced walls. No empty baskets were discovered in either the walls or the mattresses under the RSP. Of the test panels, zinc-coated wires are corroded, undamaged PVC-coated wires were OK. PVC-coated mattresses under the 8-ton RSP are also mostly OK. Severe storms in January 1997 caused about 40 slides along the Pacific Coast Highway. One slide about a mile north of the north gabion wall was called the Duck Pond slide, [Duffy, reference 19], and about 9 acres (1.5 million cubic meters or 4 million tons) of earth moved. The toe of the slide was in the ocean, and as reported by Jim Krenkel of the Caltrans Willow Springs Maintenance Station, the normally rocky beach below the gabion walls filled with a 10-foot thick layer of slide material, and after 2 or 3 days the beach returned to its prior level. As seen in the photos, there was displacement of a few less-massive rocks in the RSP revetments, but overall, the revetments are OK.

As confirmed by Mike Eul of the Willow Springs Maintenance Station in May 2001, after 16 wet seasons the 2 gabion walls and the 2 RSP revetments are mostly OK. During the wet season of 2000-2001, there was one storm with above normal waves that displaced some of the rock of the north RSP, and some mattresses were exposed.

Because site 7 received storm waves, splashes, and direct salt spray on very windy days, there was advanced atmospheric corrosion of zinc-coated test panel wires. We do not have precise counts of the number of storm events that caused waves to splash and run-up on the walls, however we estimate that those were not frequent occurrences. If there were many prolonged direct wave attacks, soil test results (Figure 3-3 and Table 3B) indicate that there would most likely have been abraded wires along the wall faces. In the wave breaking zone on the north RSP, measurements of chlorides, salinity, and dissolved oxygen were high, as we expected. See Table 3C.

The tensile and t-test results in Table 3E-7 do not appear to be too unusual. Undamaged PVC-coated wires are performing well, because exposure to waves is not constant or direct. The walls are attacked from high seas during storms (and not twice daily at high tide). Wave energy is dissipated by the rocky beach. Zinc-coated wires are doing as expected, corroding and losing strength. For PVC-coated wires, the apparent gains of AFTER wires (remnant of mattress found on beach near 8-ton riprap and south wall test panels) are likely from larger diameters than BEFORE wires, as at site 6. Also, the mattresses were from different manufacturing runs than the test panel BEFORE wires. Therefore, the tabled values should not be considered as absolute, valid comparisons.

Sediment from the Duck Pond slide was washed into the voids among the riprap by wave action. We were unable to dig through about 6-feet of sand and gravel to collect a sample of the mattress wire, near where we sampled it in 1992. As reported in [Racin, reference 6], an intertidal set of mattress wires lost about 16 percent of tensile strength after 7 years of exposure. We tensile-tested the "remnant found on beach", which was above normal high tide, and its strength loss is comparable to the strength loss of the test panels which are attached to the walls, which is reasonable. While we were unable to sample the mattress in the intertidal zone, we compared the then present toe (Nov 1998) to post-construction photos, and we saw that the toe of the north RSP is fairly stable. We deduced that the gabion mattress layer is still functioning well. For the south RSP, a similar overall assessment using post-construction photos indicated its toe was also fairly stable, and its underlying mattresses are also functioning well.

The blazed sample represents wires with damaged coatings, as seen on the corners and treads of the wall steps, where rocks impacted the structure. The larger loss of tensile force is not unusual, considering that damaged PVC allows electrolyte to enter and remain, as contrasted to zinc-coated wires which may dry-out more readily after being doused by waves.

See photos 83 through 101 and captions for details of local exposures at Site 7.

TABLE 3E-7. Pacific Ocean Near Alder Creek Tensile and t-Test Results

A	B	C	D	E	F
7 mattress under north RSP 05-MON-1 7.5 beach, Pacific Ocean near Alder Creek	5	12.93	not mic'd	ntd	Mattress in intertidal zone not accessible, buried with sediment from Duck Pond slide, up to 6-feet higher than normal high tide elevation. Mattress protected from direct wave attack by 8-ton RSP
remnant found on beach	5	12.93	101 106 106	YES	705 621 5.02 +13.53 undamaged PVC-coated wire OK
7 south and north walls 05-MON-1 7.7/8.1 beach, Pacific Ocean near Alder Creek	5	12.93	not mic'd	ntd	retaining wall wire not sampled. wall faces have same exposure as test panels
7 south wall test panels 05-MON-1 7.7	4	12.05	not mic'd	YES	714 816 6.12 -12.5
beach, Pacific Ocean near Alder Creek	5		101 105 106	YES	671 621 5.02 +8.05
7 north wall test panels 05-MON-1 8.1	4	12.05	not mic'd	YES	708 816 6.12 -13.24
beach, Pacific Ocean near Alder Creek	5		101 105 106	NO	653 621 5.02 NCD
7 north wall BLAZED panel 05-MON-1 8.1 beach, Pacific Ocean near Alder Creek	5	12.05	not mic'd	YES	407 621 5.02 -34.46 very rusted at BLAZE

See page 30 for :
TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Site 7   Pacific Ocean Near Alder Creek   05-MON-1   post mile 7.5

Photo 83. Building north RSP, looking southerly, nonwoven geotextile, PVC-coated gabion mattress product 5, Method A 8-ton rock slope protection (RSP), 7 Aug 1985. Laborers secured lids of baskets with 13.5-gage PVC-coated tie wire. Gabion and rock toe at 0 feet elevation, mean sea level (MSL).

Photo 84 (left image). North RSP 4 wet seasons after completion, 1 May 1989, looking southerly, incoming tide. Normal daily high tide reaches above elevation 6 feet, saturating toe. Lower road at elevation 30 feet.

Photo 85 (right image). Confirmed 8-ton rock mass during 7th wet season, 27 Jan 1994. Smaller rock that was chinked among voids washed away and larger rock shifted, partially exposing some gabions. At toe near middle of north RSP (circle in photo 84).

Photo 86. North RSP and gabion mattress mostly OK after 13 wet seasons, 4 Nov 1998, looking southerly. Waves reached higher than elevation 25 feet in January 1997 storm that caused Duck Pond slide (about 1 mile northerly), beach received about 10 feet of sediment, eroded and stabilized after 3 days. Beach cycles between scour and accretion, shown here with about 6 feet of accretion (left of arrow).

Photo 87. Normal high tide, waves break directly on south RSP, a deepwater revetment, looking northerly, mostly OK after 13 wet seasons, 4 Nov 1998. Nearly same cross-section as north RSP, except toe of PVC-coated gabion mattresses are at elevation 10 feet, 8-ton rock toe extends below mattresses.
Duck Pond slide (Jan 1997) is bare land feature in far left background on point, more than 1 mile distant.
Access to north RSP down steep grade from route 1, through rock cut, then to right.

Photo 88. South RSP, looking northerly, rocks missing near top of revetment, some gabions exposed, 4 Nov 1998. Light rock displaced from lower part of revetment by above-normal waves of January 1997 storms, then rocks above the displaced lower rocks fell down slope, exposing mattresses. We saw one exposed zone among south RSP, while we saw several exposed zones among north RSP.

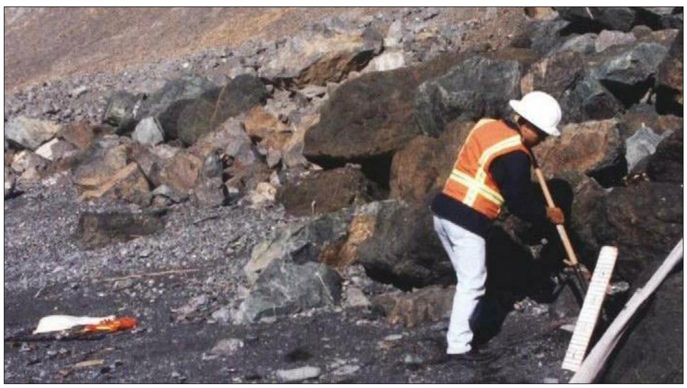
Photo 89. Building north wall with PVC-coated gabions, product 5, on 7 Aug 1985, looking northerly, near post mile 8.1. Base tier completed of 7-tiered, step-faced wall, bottom gabions at about elevation 4 feet.

Photo 90. Oblique aerial view of south wall after about 1 wet season. 24 March 1986, looking easterly, post mile 7.7. Normal daily high tides reach about elevation 6 feet, rocky beach buffers wall from daily wave attack. During severe storms, waves reached top of wall, about elevation 25 feet, occasionally overtopping wall.

Photo 91. View of north wall during normal high tide, fog bank off shore. 4 Nov 1998, looking northerly, post mile 8.1. Cyclist on road (circle). Cobbles and rocks up to about 1-foot effective diameter fall on wall steps.

Site 7   Pacific Ocean Near Alder Creek   05-MON-1   4 Nov 1998

Photo 92. South wall (arrow) during normal high tide, north wall (box). Wave energy dissipated on rocky beach. Looking northerly, post mile 7.7. Part of Duck Pond slide visible (upper left). Camper (circle) parked on shoulder near steep slope above Alder Creek culvert outlet.



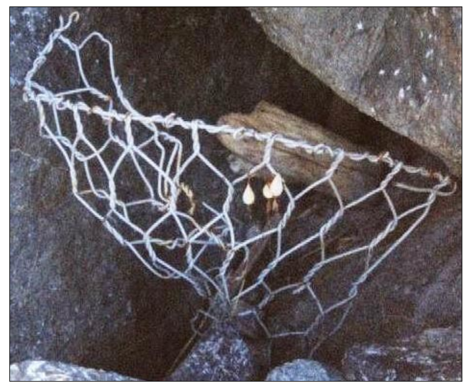


Photo 93 (left image). Searching for mattress sample below high tide elevation among 8-ton RSP. Mattresses below high tide were buried in about 6 feet of material from Duck Pond slide. Looking northerly, post mile 7.5.

Photo 94 (right image). Collected mattress remnant in rock void, likely from initial construction, but above normal high tide, old dried kelp on mesh. Represents wire with undamaged PVC coating. Post mile 7.5.

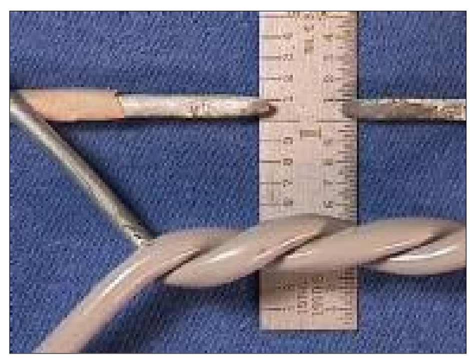


Photo 95 (left image). Blazed wire (top) represents damaged PVC, like wires impacted by rocks, see photos 97 and 98. Blazed wires lost about 35 % tensile strength after 13 wet seasons. Top and middle wires tensile-tested. All zinc at blaze was sacrificed, remaining zinc on wire was too far to offset local corrosion attack, where wire broke. Contrast left part of control wire pair (shiny, PVC stripped), to left part of middle wire (dull gray with white corrosion compounds, PVC stripped), where electrolyte got in space between PVC and wire.

Photo 96 (right image). Top wire (tensile-tested) from mattress remnant, see photo 94. Represents undamaged PVC-coated wires, which are protected from direct wave attack by rock revetment. No detectable loss of tensile force after 13 wet seasons, similar to wires from panels and walls with intact PVC. White compounds indicate early state of corrosion (likely zinc oxide, zinc carbonate, and/or zinc sulfate).

Photo 97. Corners and tread (horizontal portion) of stepped walls are intermittently impacted by rocks. Rocks slough from slopes above walls. Pacific Coast Highway is about elevation 60 feet. Top of wall is about elevation 25 feet, approximate reach of storm waves.

Photo 98. Observer points-out where sloughed rocks severed some gabion wires, gabion rock-fill is still contained. North RSP (arrow) is about ¼ mile distant. Both walls are OK after 16 wet seasons (assessed by maintenance, May 2001), despite broken wires from rock impacts.

Photo 99.
Test panels after 6 wet seasons, 10 Nov 1992.

Test panels of products 4 and 5 fastened to both north and south walls in 1986.

PVC-coated panels fastened to face panels on wall tiers 2 and 4 from top, zinc-coated panels (rust visible) on tier 3.

Wire samples collected on 4 Nov 1998 and remainder of test panels left in place.

Observer points to interlocking fasteners, see photo 100.

Photo 100.
Tiger-tite™ interlocking fasteners.

Both zinc-coated and stainless steel interlocking fasteners were hung by test panels on tier 4 of wall, elevation 13 to 16 feet, 10 Nov 1992. See photo 101.

Photo 101. Zinc-coated (left) and stainless steel (right) Tiger-tite™ interlocking fasteners.
After 6 years of exposure to local atmospheric conditions (frequent coastal fog), storm wave splash, and submerged occasionally by waves and above-normal tides,
4 Nov 1998.
Nearly actual size, when printed as image on 8.5” x 11” page.

SITE 8

The exposure of site 8 is a road fill slope in Furnace Creek Wash in Death Valley, California. The average annual rainfall as measured at the Furnace Creek, Death Valley National Monument Park Headquarters and visitor's center is about 2.4 inches. This arid region of California gets most of its rain from about July through September. The storms may cause flash floods in the normally dry washes (arroyos) like Furnace Creek.

Furnace Creek intercepts (impinges on) the road which then flows parallel more or less with the road. There were frequent wash-outs near the junction of Ryan's Wash and Furnace Creek Wash, which is also at the junction of State Route 190 and Dante's View Road. Instead of rebuilding the road at grade, route 190 was rebuilt on a fill about 5 feet high, and the side slopes were protected with 1-foot high gabion mattresses. The mesh is welded square grid, 11-gage wire, zinc-coated (class 3, 0.8 ounces per square foot), with gray PVC coating, and it was produced by the manufacturer of product 3. Soil test results in Figure 3-4 and Table 3-B indicate particle sizes that are abrasive when they are transported by flash floods. The additional PVC coating was required to provide some abrasion protection for zinc, after a layer (1 to 4 feet thick) of native soil washes away in floods. Burying the gabions was required by the Death Valley National Park staff for aesthetics.

The tensile and statistical results in Table 3E-8 were based on a variation of the t-test, the tau sub-d test for very small data sets. The BEFORE tensile values came from contract compliance tests, and the wires were sampled from gabions that were delivered to the job site (See Note 1 below). The tau sub-d test suggests that there is a difference between BEFORE and AFTER strength values. There appears to be a 5.56 percent gain in strength AFTER exposure. The data-set is too small to calculate a realistic coefficient of variation for detecting a gain or loss of strength, and if we assume the same coefficient of variation as product 3 of 5.69 percent, (because the mesh was produced by the manufacturer of product 3), then no difference is detected. However, it may be possible that there really was a gain of strength due to strain aging, as noted in the site 6 discussion on page 53. See photos 102 through 110 and captions for details of local exposures and effects at site 8. There was not enough flash flooding during the 4-year observation period to see any significant differences in the wire or the whole facility, other than some of the cover fill washed away and may need to be restored.

TABLE 3E-8. Furnace Creek Wash Tensile and t-Test Results

A	B	C	D	E	F
8 Furnace Creek Wash 09-INYO-190 122.3 mattress side slope/channel lining, buried with native channel materials.	1 P V C	4.19	116 120 122	YES	Only 3 data values, BEFORE mean=934, AFTER mean=989, no coefficient of variation, apparent 5.56 % gain. For very SMALL data sets, tau sub-d criterion is n1=n2<=10. The ultimate tensile force values were : (n1=3 values) BEFORE 931 934 938 (n2=3 values) AFTER 984 989 994 tau sub-d = 3.24, a/2 = 0.025 (2-tailed test), tau table = 0.636. Calculated tau > tabled tau, which suggests that we reject the null hypothesis (means not different) and accept alternative hypothesis (means are different).

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11, except column F entries are explained.

Note 1. We also did 15 weld shear tests, and all weld shears were greater than 663 pounds, which exceeds the required minimum of 600 pounds for 11-gage wire in the Caltrans gabion specifications.

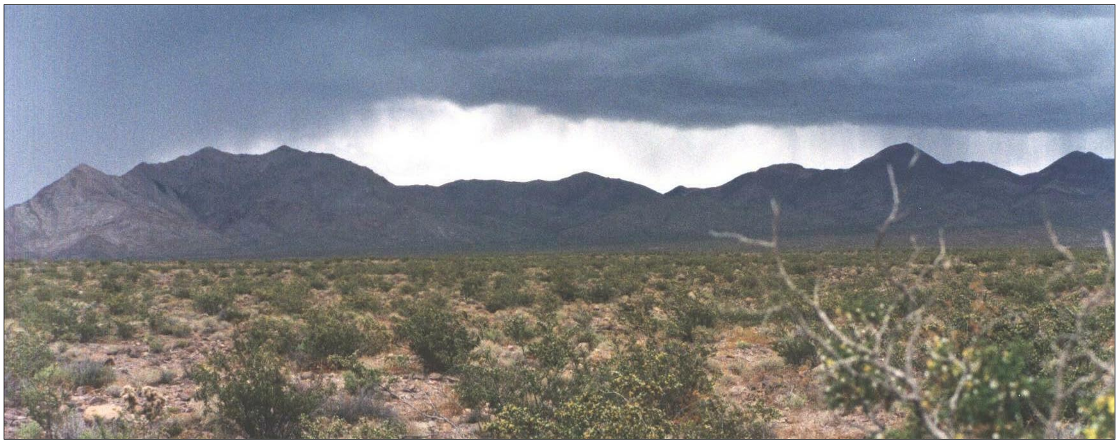


Photo 102. Thunder storm in Death Valley National Park, 9 Jun 1998. Intense rainfall may generate flash floods that convey sediment-and-debris-laden runoff over sparsely vegetated, erodible desert lands.

Photo 103. Furnace Creek Wash looking upstream (easterly), 4 May 1987.

Flash flood washed away about a ½ mile of road shoulder.

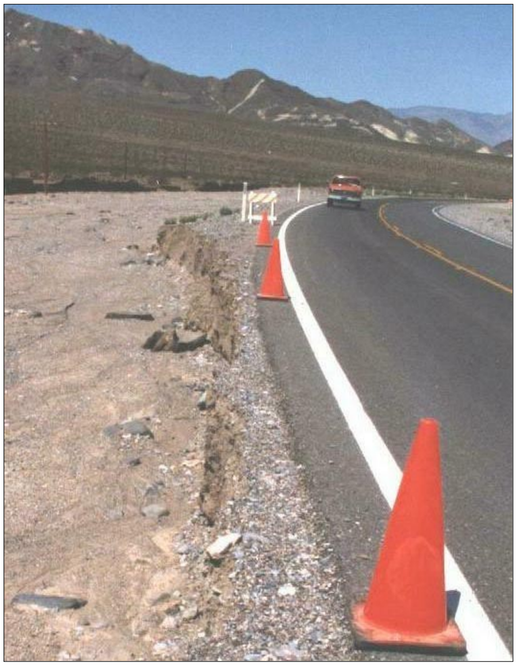
Sign (arrow) indicates right turn (southerly) after curve onto Dantes View Road to Billie Mine (3 miles) and Dantes View (13 miles).

Photo 104.
Furnace Creek Wash looking downstream (westerly), 4 May 1987.

Drop from the road to flow line of wash ranged from about 1 to 5 feet.

Because road is in Death Valley National Park, visitors are restricted to travel only on pavement. All off-road travel is forbidden, however, shoulders may be used for emergency stops.

Caltrans maintains the road under a special permit, and the shoulder had to be restored.



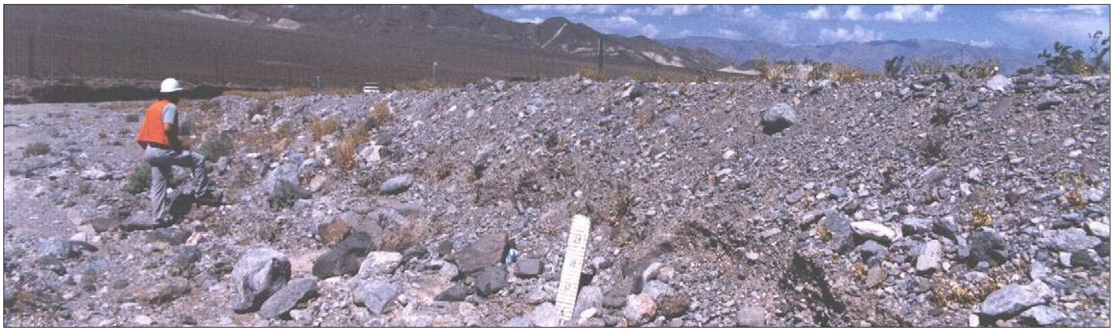


Photo 105. Looking downstream, westerly, buried gabion mattress (made of 11-gage PVC-coated welded square grid mesh, similar to product 3) protects road slope. 30” high scale (bottom center). Permit required gabion rock and cover material to match local material. Also, gray PVC-coated gabions had to be buried. Compare to photo 104.

Photo 106. Part of cover material eroded, about 500 feet downstream of photo 105, looking downstream, westerly. Gabions built on 2H:1V slope, exposed at far right of image and by researcher.

Photo 107. Collecting soil sample, looking upstream, easterly. Shovel at approximate edge of 3-foot by 3-foot counterfort (OK, buried). Flash flood impinged and combined with parallel flow, drainage paths visible from right to left and from left of center. Compare to photo 103.

Photo 108. Removed sample from gabion mattress lid. Gray PVC-coated, 3” x 3” welded mesh.

Photo 109. Repaired cut-out zone with interlocking fasteners and special long-handled pliers.

Photo 110. Completed repair. One stainless steel interlocking fastener placed in each mesh opening.

SITE 9

The exposure of site 9 is very similar to site 8. Gower Wash (an arroyo) crosses Route 190 near Zabriskie Point, about 7 miles northwest of site 8. The average annual rainfall as measured at the Furnace Creek, Death Valley National Monument Park Headquarters and visitor's center is about 2.4 inches. This arid region of California gets most of its rain from about July through September. The storms may cause flash floods in the normally dry washes (arroyos).

As reported by Caltrans District 9 staff, the road washed-out in early 1983 near Zabriskie Point, a scenic tour stop. A Caltrans Maintenance crew replaced the missing road fill and constructed 1-foot high gabion mattresses made from product 4 as slope protection. Since the repair, flood waters from Gower Wash cross the road, then cascade down the gabion-lined slope. Field assessment and laboratory soil test results (Figure 3-4 and Table 3B) confirm that soil particles are large enough to abrade wires when transported by floods. There are a few mattress lids that failed by abrasion. At the bottom of the slope, the gabions end at a 4-foot drop, and not too far downstream is the confluence with Furnace Creek Wash. The downstream channel (Gower Gulch) is very narrow and deeply incised. No test panels were attached to this gabion facility, however a few wires were collected from one of the failed lids. The condition of the facility is mostly OK. Some zinc (likely zinc carbonate) is still visible, even on the sampled wires. The tensile and t-test results are consistent with the local exposure, infrequent flash floods. See Table 3E-9.

Recent discussions with Truman Denio, Caltrans District 9 hydraulic engineer in Bishop, CA, indicate that Furnace Creek was diverted decades ago to flow into Gower Gulch. Furnace Creek Wash more or less follows Route 190 almost to where Gower Wash crosses Route 190, however, Furnace Creek Wash flows away from the road and joins Gower Wash a few hundred yards southwesterly of Route 190 in Gower Gulch. The additional flow apparently contributes to the headcut (upstream progress of channel incision), which the gabions stop at the toe of the road slope in Gower Wash. There is a study by the Park Service to re-route flow away from Gower Gulch, which would restore Furnace Creek Wash, so it ultimately flows past the Furnace Creek Inn and Ranch Timbisha Indian Reservation, essentially following its original drainage path. See photos 111 through 115 and captions for details of local exposures and effects at site 9.

TABLE 3E-9. Zabriskie Point Tensile and t-Test Results

A	B	C	D	E	F
9 Gower Wash 09-INYO-190 115.3 near Zabriskie Point Death Valley National Park mattress invert/channel lining	4	15	116 110 112	NO	782 816 6.12 NCD not buried, wires partly abraded, some failed lids, most of facility OK

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11.

Photo 111. Flood washed-out road in 1983. Looking up-slope and upstream on 9 Jun 1998, at road fill protected by 1-foot high zinc-coated gabions, product 4. Flood waters in Gower Wash originate in mountains (distant background) and then flow across road (pick-up truck in center of channel on opposite side of road).

Photo 112. Researcher (center) stands on top of last row of gabions, looking down-slope (from road shoulder in photo 111), 9 Jun 1998. Gully at left is seen on right in photo 114.

Photo 113. Headcut stopped at toe of slope, gabions not undermined, 9 Jun 1998. Tour bus on road.

Photo 114. Gabion-protected slope is spillway-downdrain for flash floods, looking up-slope and upstream in Gower Wash (gully at right is seen on left in photo 112), 9 Jun 1998. Some lids failed due to abrasion by sand and gravel transported during floods. Brownish color is silt residue, and some rusted wires.

Photo 115. Collected wire samples from failed lid (failed basket seen at lower left in photo 114), 9 Jun 1998. Most wires still had some zinc (dull gray color, likely zinc carbonate), indicating low frequency of abrasive, flash floods. 30” high x 5” wide plywood scale is marked in inches.

SITE 10

The exposure of site 10 is in the foothills south of the Trinity Alps Wilderness along Route 299 in northern California. The average annual rainfall as measured at the Trinity River Hatchery is about 34 inches. As part of a curve correction, a road fill about 100 feet high was built. To convey runoff from cut slopes and the roadway, and to collect any incidental surficial slope erosion until vegetation could establish, an open channel gabion downdrain was built, similar to the downdrains along the Redwood Park Bypass (site 3), except the mesh is product 1, zinc-coated 11-gage welded square grid. The typical channel cross-section is trapezoidal, bottom width is 3-feet, depth is about 1.7-feet, and side slopes are 1.5H:1V. The gabion drain connects to Sawmill Creek which is conveyed under Route 299 in a 96-inch culvert.

The gabion downdrain is performing well. Runoff energy is dissipated continuously in the rock-filled gabion baskets and counterforts. Starting at the toe of the downdrain, counterforts (also called shear keys) are spaced 43-feet on-center, are 6-feet long and 3-feet high, and are built below the profile grade of the bottom of the 1-foot high mattresses. The runoff path is down a 2H:1V slope, 100-foot change in elevation to Sawmill Creek. No failures were found, and there was no major distress during the observation period. As at all other sites where zinc-coated mesh gets exposed to air, there was atmospheric corrosion of wires that made the zinc dull gray. There was some loss of zinc due to abrasion in the culvert splash zone, within 6-feet of the 24-inch bituminous-coated culvert outlet that empties into the top of the gabion downdrain. The culvert conveys storm runoff from uphill cut slopes and Route 299. No base flow (non-storm runoff) was ever seen in the culvert or the gabion downdrain, and neither was ponded water ever seen in the gabion channels. The roadway and cut slopes are less than 5 acres, so the peak flow rate is relatively small. We do not have precise counts of the number of flow events, so we simply state that runoff was intermittent. No soil was collected at this site and no water measurements were done. However, the designers apparently expected corrosive soil from the cut slopes, based on the presence of the bituminous-coated culvert. A field assessment of soil particle sizes indicated that there are materials larger than fine sand to cause abrasion, and we did see that zinc was abraded from the underlying steel wire in the 6-foot splash zone at the culvert outlet. There was no significant reduction of wire diameter, as compared to wires not in the splash zone. No wire samples were collected for tensile testing. See photos 116 through 127 and captions for details of local exposures and effects at site 10.

Photo 116. Building an open channel gabion downdrain, Sep 1987. First welded mesh gabion downdrain in Caltrans, made from product 1. Trapezoidal section, 1-foot high mattresses, 15H:1V side slopes, 3-foot wide bottom, woven filament geotextile underneath, 3' x 3' x 6' long counterforts every 43 feet. Longitudinal (downhill) slope is about 2H:1V. As with most culverts, installation proceeded from low to high elevation.

Photo 117. Completed gabion downdrain, looking downhill, Oct 1987. Culvert and downdrain have some overspray from recently applied erosion control materials.

Photo 118. Same view as photo 117, looking downhill, after 8 wet seasons, 4 May 1995.

Photo 119. Completed gabion downdrain and slopes, Oct 1987. Road cut (top center of image) part of relatively small drainage area (less than 5 acres) that drains to culvert at top of downdrain.

Photo 120. March 1988, gabion downdrain trapped sediment during 1st wet season. Sediment from eroded embankment (right) 15H:1V, gabion downdrain slope is 2H:1V.

Photo 121. Same view as photos 119 and 120 after 6 wet seasons, 22 June 1993. Slopes OK.

Photo 122. 24” bituminous-coated culvert collects cut-slope and roadway runoff, then discharges to gabion downdrain, 4 May 1995. Culvert extends beyond top of downdrain by 2 feet, prevents undermining, splash zone extends 6-feet downhill from culvert outlet, runoff flows into rock-filled gabions, energy is dissipated.

Photo 123. After 6 wet seasons, culvert conveyed relatively small amounts of sediment, as seen by evidence of very little abrasion on the culvert invert, where zinc was still present, 22 Jun1993.

Photo 124. Rusted wire at edge of splash zone (downhill at top of photo), after 12 wet seasons, 28 May 1999. Zinc (dull gray, likely zinc carbonate) still present (by shiny quarter) indicates relatively little abrasion. Rusted wire diameters not significantly different than wires with zinc.

Photo 125. Sediment trapped in gabions continues to support vegetation.
Gabions and slopes OK after 12 wet seasons, looking downhill, 28 May 1999.

Photo 126. Downdrain outlet looking downhill into Sawmill Creek, flow is from right to left, 16 Feb 1996.
Moss-covered top of culvert wingwall (top left center of photo).

Photo 127. White hard hat (circle) at end of gabion downdrain and edge of Sawmill Creek.
No evidence of sediment in creek from downdrain, 16 Feb 1996.
30” high x 5” wide white scale near inlet to 96” diameter structural steel plate pipe.

SITE 11

The exposure of site 11 is a creek bottom in Cholame Creek near the town of Shandon, California, not too far from the James Dean Memorial on Route 46. The average annual rainfall as measured at Paso Robles is about 15 inches. In this semi-arid region of California, creeks and rivers may be just a trickle in the summer and late fall. There are no dams upstream of the Cholame Creek bridge 49-0095, so uncontrolled peaks of runoff scoured the channel bottom around the bridge piles and undermined the toes of the abutment fill protection. Because there was gravel mining downstream, and because the creek is somewhat constricted at the bridge, the creek bed degraded (its elevation dropped) 11 feet in 40 years. The stability of the bridge was threatened, and until new bridges could be built, temporary scour countermeasures were needed.

To maintain a stable creek bed and soil support for the piles, check dams were built in 1996 both upstream and downstream of bridge number 49-0095. The check dams raised the creek bed elevation by about 4 feet to elevation 1024 feet. When there are storm events that are large enough to transport sediment, after flood waters recede, the sediment is retained by the check dams. The downstream check dam is made of sheet piles and riprap, and the upstream check dam is made of gabions and riprap. Geotextile, gabions, and riprap were also placed to bolster sacked concrete bank protection along the previously undermined abutment fills. Later, scour instrumentation and an action plan to close the bridge was added as another countermeasure. Construction of two new bridges is scheduled in the near future.

Soil test results in Figure 3-3 and Table 3-B indicate silty sand, which is abrasive to zinc and steel wires when it is transported by runoff. The low value of minimum resistivity (less than 1000) and other soil variables indicate that additional corrosion protection, PVC coating, would likely extend the service life of a gabion facility in Cholame Creek. We emphasize that the check dams, including the gabions, are temporary. Long service-life was not a criterion for material choice, so zinc-coated 11-gage mesh was selected and used (product 4), instead of PVC-coated mesh. PVC-coated mesh is usually more costly, and estimates vary, however it was about 30 to 50 percent more costly than zinc-coated mesh in 1996. If the facility were considered more permanent, we may have suggested using riprap exclusively.

The tensile and statistical results in Table 3E-11 indicate there is no problem with the mesh after 2 years of burial in the creek bed. Wire samples were collected from the upstream check dam, and that was repaired. There appears to be a 9 percent gain in strength AFTER exposure, and it may be possible that there really was a gain of strength due to strain aging and other effects (larger diameters, different heat of steel, etc.) that we discussed for wires at site 6. See page 53.

The check dams functioned well in the high runoff events of January 1997. See photos 128 through 133 and captions for details of local exposures and effects at site 11. Under the direction of engineering staff of Caltrans Structure Hydraulics and Translab Instrumentation, the District 5 bridge crew installed an acoustic stage gage and other bridge scour instrumentation in spring 1999, which sensed and recorded data continuously. There were no other large flow events recently to further test the temporary scour countermeasures.

TABLE 3E-11. Cholame Creek Tensile t-Test Results

A	B	C	D	E	F
11 Cholame Creek 05-SLO-46 48.3 westbound check dam buried in channel	4	2.17	not mic'd	YES	890 816 6.12 + 9.07

See page 30 for :

TENSILE and t-TEST FOOTNOTES. KEY to Column Entries in Tables 3E-1 through 3E9, and 3E-11

Photo 128. Looking downstream over sheet pile check dam. Piles of bridge 49-0095 were exposed, because creek bed degraded from downstream gravel mining and constricted channel. Check dams built in 1996 upstream and downstream of bridge, temporary scour countermeasures. Creek bed elevation raised 4 feet to about elevation 1024 feet. Prior 1-ton riprap around pier washed downstream (arrow).

Photo 129. Looking upstream through weir notch in sheet piles. Weir notch controls low flow rates, limits opportunity for creek to erode ends of check dam. Sacked concrete bank protection was undermined, also repaired. 2-ton riprap dissipates flow over sheet piles, OK after high flows of January 1997. See photo 130.

Photo 130. Looking upstream, to assure soil support around piles, a level-crested gabion check dam near researcher, (circle) was built from product 4. Riprap was placed up-and-downstream of the gabion structure. Both check dams OK after high flows of January 1997, high water mark (line) just below light paint on pier wall. Creek bed elevation was maintained at planned elevation of 1024 feet. RSP-fabric used for separation and filtration at both check dams and also around pier with 2-ton rock. Bridge will be replaced.

Photo 131. Found gabion check dam buried about 0.5 foot, looking upstream. Wire in very good condition after 2 wet seasons. Trickle flow meandered to opposite side of creek, soil was saturated. White-to-black natural gas pipe (arrow) exposed in degraded creek bed.

Photo 132. After collecting sample of check dam, lid panel was repaired with new section of product 4, 11-gage zinc-coated mesh and interlocking fasteners.

Photo 133. After repairing check dam, channel bed was restored to prior condition.

SITE 12

The exposure of site 12 is at a bridge and urban creek in Vacaville, California : Interstate 80 bridges 23-0052 left and right over Ulatis Creek. The average annual rainfall as measured at Vacaville is about 26 inches. The Ulatis Creek Watershed is network of creeks and channels that are managed by the Solano Water Agency. Segments of several creeks were channelized and straightened in the early 1970's for irrigation and flood control. When a formerly meandering reach is shortened, stream energy comes to equilibrium by scouring the bed and/or the banks. Realigned reaches were designed for events of a 10-year return interval with a few feet for freeboard. Despite building a few grade control structures in the 1970's at a few locations, many creek beds degraded several feet, that is, bed elevations dropped.

At the I-80 bridges over Ulatis Creek the bed degraded and surface runoff eroded the abutment fills (roadway approach embankments under and alongside the abutments). Both bridges are scheduled for replacement in 2007, and until they are replaced, temporary bridge scour countermeasures were needed. Because local soils are fine-grained and clayey (field assessment, potentially corrosive), and because the schedule for replacement is about 6 years later than site 11, PVC-coated gabions made from product 5 were selected for the scour countermeasures. To maintain soil support around bridge piles, sheet pile check dams were built both upstream and downstream of the bridge, as grade control structures to arrest local creek bed degradation. To stabilize abutment fills, the slopes were lined with gabion mattresses. Gabion walls were built to confine both sides of the creek under the bridge in the relatively narrow channel (bottom width about 30 feet). No test panels were placed at this site.

As seen in the photos, several gabions failed due to vandalism, gabion-to-gabion joints were improperly tied, and the geotextile under the slope mattresses will not perform as a filter, because it has a very low permittivity (about 0.07 per second according to ASTM D 4491). In bridge inspection reports, repairing the vandalism and retying the incorrectly formed joints was identified as work recommended. Until the bridge is replaced, the gabion countermeasures should be monitored for any further vandalism or embankment saturation stress. See photos 134 through 143 and captions for details of local exposures and effects at site 12.

Photo 134. Looking downstream under bridges 23-0052 left and right, after one wet season. Temporary bridge scour countermeasures: steel sheet pile check dams upstream and downstream for creek grade control, gabion walls (channel sides) and mattresses (abutment slope protection) made from product 5. Runoff event of January 1997 near Q100 flowrate and stage, reached upper portion of slopes near piers 2 and 5 (arrows). Downstream rock is remains of sediment-filter device used in construction. There were about 10 vandalized gabions, one is dimpled and partially empty slope mattress (box) between first two columns at right.

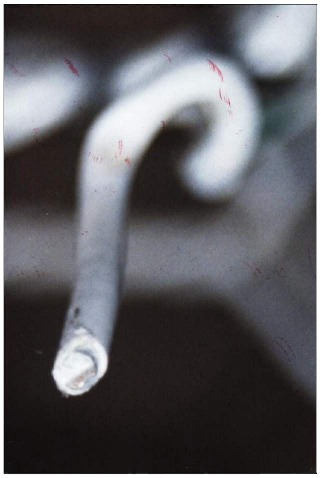


Photo 135 (left image). Another vandalized gabion in wall (oval). Flow is toward left and parallels wall. Downstream sheet pile check dam matches channel cross section, a few sections protrude above mattresses.

Photo 136 (right image). Wires of partially empty and empty baskets were sheared by a cutting tool. Cut-up gabion cells were in several locations that showed no indications of hydraulic stresses or slope instability. We concluded wires were cut-up by vandals. Additional and maybe unrelated vandalism was graffiti painted on both abutments and nearly all columns. Bridges are scheduled to be replaced.

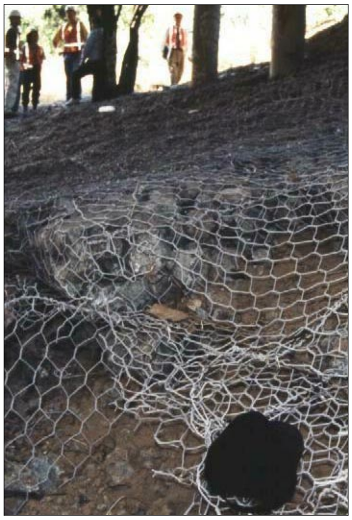


Photo 137 (left image). Vandalized empty gabions, top of wall, and no geotextile behind these empty gabion cells. PVC-coated mattress gabions extend just above Q100 stage, to protect upper slope (up to where gabions intersect pier 5 (behind observer). Black cap is for orientation in photo 138.

Photo 138 (right image). Maintenance engineers are standing just beyond bridge drip line next to tree on upstream side of bridge, see photo 139.

Photo 139 (left image). Trimming excess piece of geotextile that was wrapped around tree trunk, upstream side of bridge near Q100 stage.

Photo 140 (right image). Trimmed geotextile submitted for permittivity tests (ASTM D 4491).
Results were 0.07 per second, flow rate perpendicular to plane of geotextile, equivalent to permeability of about 0.006 centimeters per second, or about 4.9 gallons per minute per square foot.
At this site, such a woven-tape (slit-film) geotextile is not appropriate on slopes or behind walls.
A freely draining geotextile is required, like a standard Caltrans RSP-fabric with minimum permittivity of 0.5 per second, about 37.5 gallons per minute per square foot. Behind walls and slope, soils may become saturated.
Excess soil pore water pressure can then collapse the embankment into creek, when stage drops suddenly.
If slopes fail by this mechanism, it will not be because of the gabions.
Until both bridges 23-0052 left and right are replaced, monitoring is prudent.

Site 12 Ulatis Creek 04-SOL-80 post mile R42.8 5 Jun 1997

Photos 141, 142, and 143 show examples of out-of-specification joints that were typical, not exceptional.

Photo 141. First of 3 out-of-specification joints using interlocking fasteners, lack of inspection and/or attention to Caltrans plans and specs. Supplier brochure showing fasteners at 6-inch intervals is not recommended by Caltrans. Caltrans requires one alternative fastener in each mesh opening along the joint, and if one fastener can not enclose all the wires in a single pass, then standard 13.5-gage tie wire must be used.

Photo 142. Second of 3 out-of specification joints, near 73-inch mark (arrow), fastener is not interlocked, then toward right, 2 fasteners are missing. Joint near high water, submerged by January 1997 flow, as indicated by drift (floating vegetative debris left behind after flood stage drops).

Photo 143. Third of 3 out-of-specification joints, four baskets not joined at corners, where multiple basket-to-basket joint is required. It appears empty baskets were laid out and filled with rock, then rocks were crammed into void where tied joint should be. Such practice is contrary to Caltrans and most supplier specifications, which require : form single baskets, join them, slightly over fill them with rock, close and fasten the lids.

SITE 13

The exposure of site 13 is the beach at Lime Kiln Creek Campground at the Pacific Coast Highway (PCH or US 1) and the Pacific Ocean. The average annual rainfall as measured at Big Sur Station (about 25 miles northerly) is about 41 inches. Similar to site 7, this part of the California coast is often foggy, and storm waves have reached above 25 feet. No test panels were placed, and we did not sample soil or water. Soil (beach sand) and water (ocean) are similar to site 7. See Figure 3-3 and Tables 3B for soil data and Table 3C for water data. Unlike site 7, there is no rocky beach to dissipate wave energy.

The Caltrans Bridge Maintenance Book Number 24 (Office of Structure Maintenance and Investigation files) documents about 35 years of distress and repairs at site 13. Since the Lime Kiln Creek Bridge (number 44-0058) was built in 1957, the toe of the 100-foot high northerly and westerly fill slope has eroded. Originally, 4-ton rock slope protection (RSP) was placed along the toe, with no filter layers or geotextiles (none available then). During storms, waves and splash were seen higher than elevation 25 feet. Slope and roadway distress began in 1958, a year after the bridge was completed. By 1963 there was significant loss of upper slope material along the toe of an upper slope crib wall. A sinkhole (5 feet x 5 feet x 15 feet) developed in the northerly approach road at abutment 10, and the upper slope erosion exposed piles of the wing wall near elevation 90 feet. Without a stable toe (at sea level), material sloughed, and after 6 years, the entire slope was steep and unstable. On 7 January 1974 a major slipout occurred, and by 9 January 1974 work began to stabilize the toe of slope with a 150-foot long concrete crib wall and RSP. The "sea-level" crib wall was built from about elevation 5 to 25 feet with a concrete splash apron that extended to about elevation 40 feet. The splash apron soon needed repair, because it was undermined by slope runoff. To protect the toe of the wall from wave attack, concrete was placed from about elevations 3 to 9 feet by about 20 feet wide and more than 150 feet long, beyond the length of the wall.

In late 1983 storms attacked an additional 150 feet along the toe of slope, south of the sea-level crib wall. The already over-steepened slope sloughed enough soil to expose 7 feet of the first row of piles at bent 9. Piles at bents 7 and 8 and abutment 10 were close to being exposed. To repair the toe erosion, a new sea-level crib wall was built. It connected to the old sea-level crib wall and extended about 150 feet southerly. By 1988, the new wall was completed. Instead of placing concrete or large rock at the toe of the new wall, a design requirement was to maintain the private (at that time) campground low tide beach. So, a 12-foot wide gabion apron (product 5) was cabled to the toe of the new crib wall, and it was covered with about a foot of beach sand. By 1990 the first sign of gabion distress was seen : PVC and zinc coating were abraded, where storm waves had washed away the sand cover. By 1994 wires were rusty, there was a visible loss of wire diameter, and wires of several baskets were broken. By spring 1995, after 6 wet seasons, some gabion baskets were missing. Along the lower 6 feet of the wall, there were concrete spalls where rebar was exposed, due to boulders being tossed against the wall by waves. Concrete of the crib members was tested and found to not be saltwater resistant. As waves broke and impacted the wall, beach sand backfill in the cribs escaped from wall joints like sand in an hour glass. Consequently, several cribs were more than half empty. The new southerly crib wall had to be repaired, replaced, or buttressed. Gabions in this wave attack zone were not feasible, as contrasted to site 7, where there was enough rocky beach in front of the gabion sea walls to help dissipate wave energy.

By fall 1995, a contract was completed which buttressed the toe of slope in front of both the old and new sea-level crib walls with massive rock, an 8-ton gradation. First, crib wall voids were grouted. Second, a heavy duty nonwoven, high permittivity (> 0.5 per second) RSP-fabric (16-ounces per square yard) was placed against the walls and on the beach. Third, 8-ton RSP was placed, and it is from 13 to 29 feet wide by 5 to 18 feet high, with most of it 25 feet wide by 16 feet high. During the design phase, private ownership of the campground passed to California State Parks and Recreation. Their permit required Caltrans to place soil cover on the RSP in hopes of establishing vegetation. So, soil cover was placed from about elevation 25 feet to about elevation 6 feet, however, it did not last through the next wet season. The 8-ton RSP withstood the 1995 wet season. It also withstood the series of damaging storms in January 1997, the same event(s) that caused the Duck Pond slide near Site 7. Loose rock smaller than 8-tons is unstable at site 13. Immediately north of the old sea level crib wall, erosion continues slowly, where waves attack weathered rock, and the slope remains over-steepened. In March 2000 an inspection showed that some additional massive rock may be needed to buttress the toe of slope. See photos 144 through 157 and captions for details of local exposures and effects at site 13.

Photo 144. Distressed slope one year after construction with 4-ton RSP at toe of slope, 1958. Slope eroded (left center) and became over-steepened by storm wave attack. Looking southerly from beach at bridge number 44-0058, completed 1957. Northerly abutment 10 at upper left, piers 9, 8, 7, etc. are southerly toward right, pier 3 in Lime Kiln Creek. Elevation difference of beach to roadway is about 100 feet.

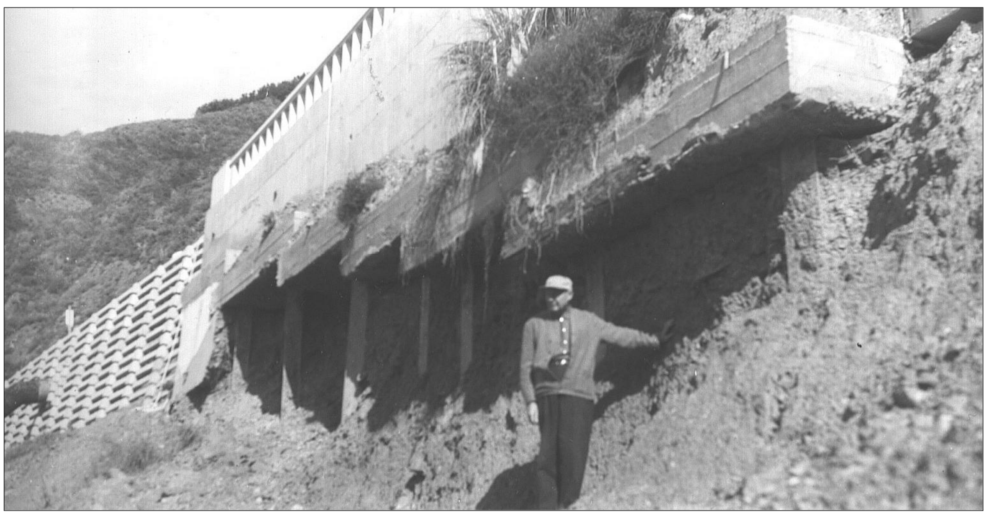


Photo 145. By 1963 after 7 wet seasons, upper slope lost a large mass of soil at abutment 10, and a sink hole was in bridge approach road (5' deep x 5' wide x 15' long).

Photo 146. On 7 Jan 1974 slope failed below abutment 10 and approach road crib walls. Looking northerly from beach. On 9 Jan 1974 dozer (circle) started grading for near sea-level crib wall to stabilize toe. Continual toe erosion, twice daily high tide to elevation 6 feet, storm waves seen higher than elevation 25 feet.

Site 13 Lime Kiln Creek 05-MON-1 post mile 21

Photo 147 (left image). Researcher (arrow) inspects failing new 150-foot long concrete crib wall, built 1988. Front closure members fell into cribs. Wall top elevation is 30 to 34 feet. Looking southerly from beach after 2 wet seasons, 25 Jul 1990. Gabions (product 5) built in front of new wall, covered with a foot of sand for recreational beach use. Mattresses cabled to wall, extended 12 feet from new wall. Concrete buttress (left foreground) built about 1976 is 150' long x 20' wide from elevation 3 to 9 feet, protects toe of old concrete crib wall from wave attack (built 1974), later faced with air blown mortar. Kelp is limit of recent high tide waves.

Photo 148 (right image). Abraded rebar (circled in photo 147) protrudes from concrete buttress and demonstrates result of repeated wave attack. Black peg book is about 5" x 3". Normal daily waves mobilize shells, sand, gravel, (boulders mobilized by storm waves) and materials impact and grind on all things in their path : walls, gabions, massive rocks, even the mixture of mobilized sediment itself.

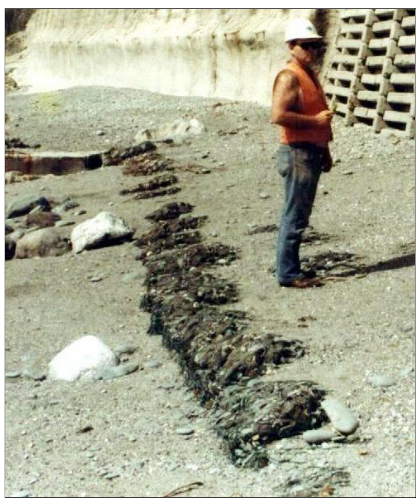


Photo 149 (left image). Gabions partially exposed after 2 wet seasons, some PVC missing, 26 Jul 1990. Wire broke (circle) possibly by rock impacts. Note particle sizes.

Photo 150 (middle image). Gabions partially exposed after 4 wet seasons, 10 Mar 1992, looking northerly. Initially a foot of sand covered 12-foot long gabions. Investigating new crib wall (sand backfill, no geotextile, waves vibrated sand, voids developed, closure members fell into voids, see photo 147).

Photo 151 (right image). Close-up of gabion wire (see photo 150), after 4 wet seasons, 10 Mar 1992. PVC is mostly gone, more than half the zinc coating is missing, some reduced wire diameters, rust is visible.

Photo 152. Partially exposed gabions (box), 10 Mar 1992, looking northerly. See photos 150 and 151.

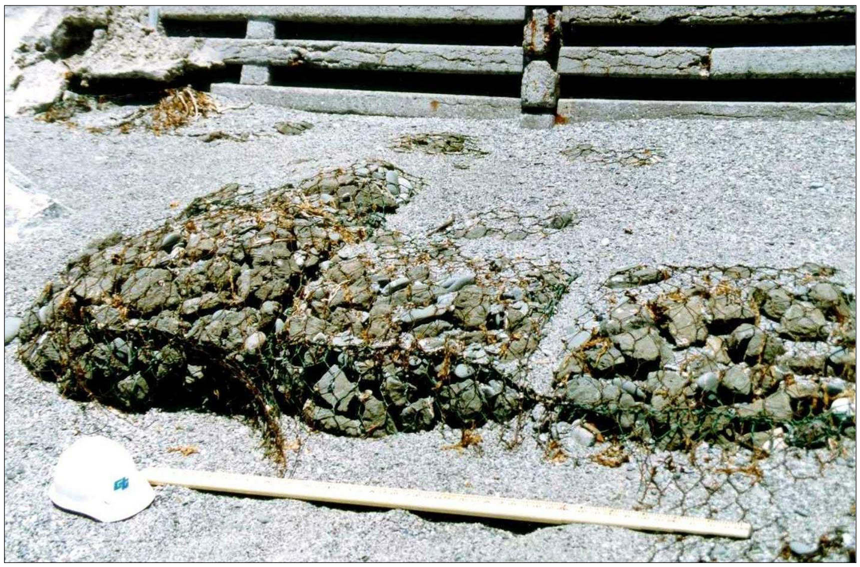


Photo 153. After 5 wet seasons, near join to old crib wall, gabions on left OK, while gabion at right failed, part of lid was opened, right foreground, 1994.

Photo 154. During 6th wet season, waves and rocks hammered new crib wall, some gabion cells were emptied by wave action, boulders were strewn about, looking southerly 15 Aug 1995. By this time, new crib wall was so distressed, it needed to be replaced or buttressed.

Photo 155. Walls buttressed by 8-ton rock, built 1995, looking northerly, 5 Nov 1998. Nonwoven, heavy-duty (16 oz / sqyd), high permittivity (>0.5 per second) RSP-fabric initially placed on beach and against walls.

Photo 156. 8-ton rock, looking northerly, 5 Nov 1998. Stable after severe storms of January 1997.

Photo 157. 8-ton rock buttress after 5 wet seasons, 14 Mar 2000, looking northeasterly. So far, rock is OK as scour countermeasure for toe of slope below abutment 10 and piers 9, 8, and 7 of bridge no. 44-0058.

SITE 14

The exposure of site 14 is in San Gregorio Creek along Route 84, about 7 miles inland from the Pacific Ocean, high enough in elevation so it is not influenced by tidal currents. Depending on where you are along its length, San Gregorio Creek provides migration, spawning, and rearing habitat for steelhead, an endangered species. The watershed is a mixture of pasture and wooded land, west of the San Francisco Bay Area. The average annual rainfall as measured at San Gregorio is about 29 inches. San Gregorio Creek and it tributaries follow their natural courses, while Route 84 parallels, crosses, and sometimes "competes" for the same space in the relatively narrow ravines. In this 61 square mile watershed, a common storm damage scenario is : the creek gets dammed by fallen trees and other woody debris, then banks become saturated, scour, and wash out. During the January 1997 storms, a debris dam formed at one of several privately-owned bridges that cross the creek for access to a home. The roadway embankment got saturated and failed, and so did the bridge.

Because the stream is habitat for steelhead, there were permit conditions and material restrictions, so RSP (rock slope protection) with RSP-fabric, concreted RSP, or a concrete wall were not selected as materials for bank protection. Instead, a 236-foot (72 m) long gabion wall was designed. Suspended sediment and bedload range in size from silt to gravel, so abrasion is likely, and the bottom tier of the wall will likely always be saturated. Based on our recent observations of abrasive and saturated exposures, we required PVC-coated mesh, and the contractor selected product 5. The wall was built (Caltrans metric standard plans and specs) only on the roadway side of the creek, while the opposite bank remained natural. In cross-section the wall has four 1-meter high tiers, with half meter wide steps on the back of the wall, and there is an RSP-fabric (geotextile separator-filter) against the fill. So toward the creek the wall is smooth-faced. Attached to the bottom tier along its entire length just below the reconstructed creek grade, is a 1 meter wide by 0.3 meter high gabion mattress, intended as a toe scour mat, in lieu of rock riprap. No test panels were placed at site 14. There are two experimental features associated with the wall : wood fascia (temporary abrasion boards) and coir (coconut) fiber rolls.

Based on the lesson learned at site 2 about abrasion, there are two 2"x12" header boards attached to the outside face of the bottom tier of the wall. The boards are secured to the outside face of the gabion wall to protect PVC-coated mesh from abrasive attack by bedload (sand and gravel) during high stage-velocity runoff events. The boards are hung on galvanized bolts that extend through the gabion cells. Bolts are fitted with large washers and nuts (both sides), so when the boards dry-rot or show excessive wear-and-tear from abrasive attack by sediment, they can be replaced. In addition to temporary abrasion boards, fiber rolls (12 and 16-inch diameter) were tied with 1/2-inch coir rope on top and in front of the toe scour mat. Fiber rolls were placed to encourage natural (voluntary) riparian revegetation for habitat and to protect fish. There is anecdotal evidence that gabions may gill and/or trap fish, and follow-up research on this possibility is encouraged.

The creek turns right (going downstream) gradually in a large-radius bend, and with the wall on the outside of the bend, about the first 75 feet are in the zone of impinging flow. By December 2000 (after being exposed to flows for 1 wet season and just starting the next), no floods were reported. Based on the height of drift on the wall, the depth of flow was about 7 feet and the channel width was about 40 feet. We estimate that the wall was exposed to velocities of at least 7 feet per second. Several fiber rolls near the upstream end of the wall were missing, apparently washed away. Scour occurred at several of the gabion toe mats, just upstream and under the newly constructed, privately owned bridge. Perhaps the initial gabion rock-fill was not "slightly over-filled" according to specifications and the runoff helped to settle the rock-fill. Or perhaps the gabion rock-fill was too small and it scoured through the mesh. In the summer of 2000, some 200-pound and heavier rocks were placed randomly upstream of the wall to create eddies and to deflect low stage currents away from the beginning of the wall. See photos 158 through 176 and captions for details of local exposures and effects at site 14.

Note. There are two interesting features and material designs nearby : one is upstream and the other is downstream of the gabion wall. Their detailed documentation is beyond the scope of our wire corrosion report, however, they are seen in the photos. As a restoration effort for mitigating the effects of the gabion wall, immediately upstream there are root wads for enhancing in-stream habitat. Immediately downstream of the gabion wall, there are 75-pound interlocking concrete armor units that are embedded in the creek bed at the toe of slope. They are intended as bank toe protection.

Photo 158.
Gabion wall (PVC-coated, product 5) built to restore road and shoulder that washed-out in January 1997. Looking downstream on 22 Jun 1999.

Constructing PVC-coated scour mats (0.3 m high by 1 m wide) at base of wall. If coir logs (see photo 160) wash away, gabion scour mats will be exposed, thereby indicating possible need to provide protection along base of wall or redirect the creek currents.

While installing scour mats some water seeped into work zone, which was isolated from low flow in creek by plywood reinforced silt-fence barrier (partly visible at upper right).

Photo 159.
Looking at downstream end of wall, 29 Jun 1999.

Temporary abrasion boards are a trial feature prompted by lesson learned at site 2. They are intended to protect gabions from abrasion. 2”x12” boards were mounted on 5/8-inch (16 mm) diameter galvanized rods that went through gabions. Washers and hex-nuts hold boards on wall and allow replacing any dry-rotted or excessively worn-out boards.

Photo 160.
Biodegradable fiber rolls (coir, coconut fiber) tied to gabions with ½-inch (13 mm) braided coir rope. 3 rolls on top and 2 rolls buried in front of gabion scour mats. Anecdotal evidence has suggested that gabion mesh may trap or injure fish. Coir logs were placed as a buffer and also to help establish natural riparian vegetation.

Looking downstream on 28 July 1999, slope covered with coir mat and staked to slope.

Photo 161 (left image). Gabion wall, gabion toe scour mats and coir fiber rolls completed, 28 Jul 1999. Looking upstream. Coir turf reinforcing mat staked to slope. Fiber rolls tied to mats with ½-inch coir rope.

Photo 162 (right image). Near end of 1st wet season on 1 Mar 2000, receding runoff, looking upstream. After mild winter and spring with no floods, fiber rolls at toe of slope and coir mat missing at downstream end of wall.

Photo 163.
Road runoff eroded slope just beyond end of gabion wall. Asphalt concrete dike placed to divert runoff into top cells of gabion wall.

Coir turf mat was replaced (see photo 162). 20 Dec 2000.

Photo 164.
Abrubt change from gabion wall transitions to stream bank with 75-pound interlocking concrete armor units (AJACKS) to prevent toe erosion beyond wall.

AJACKS extend downstream almost to natural log bridge. Average height of waterway opening under natural log bridge is about 6 feet. 20 Dec 2000.

Photo 165.
Upstream end of wall, fiber rolls distressed during 1st storm runoff which occurred on 28 Jan 2000 in the 1st wet season.

A chunk of concrete (circle) estimated as > 75 pounds was seen on fiber rolls. Possibly it was removed by subsequent storm flows, because it was not there in Aug 2000 (see photo 166).

Photo 166.
Looking upstream 2 Aug 2000 at late summer base flow in creek.

Fiber rolls missing (lower right) due to storm runoff of 1st wet season.

200-pound and heavier rocks placed randomly upstream to help divert low runoff stage from gabion wall.

Root wad project was isolated by plywood, silt-fence, straw bale barrier (arrow), which was removed before any storm flows of 1st wet season.

Photo 167.
From elevation of fiber rolls, looking upstream.
2 Aug 2000.

Bottom temporary abrasion board is missing half its width, likely cracked during construction, then washed away by storm flows. Should have been installed with bottom edge at least as low as thalweg elevation.

Trees (upper left) leaning toward creek, bed material locally scoured under roots.

Photo 168.
Receding storm runoff
1 Mar 2000
Looking downstream.

Fiber rolls separated from wall (bottom left of center).

Photo 169. Base flow rate on 2 Aug 2000, nearly same view as photo 168.

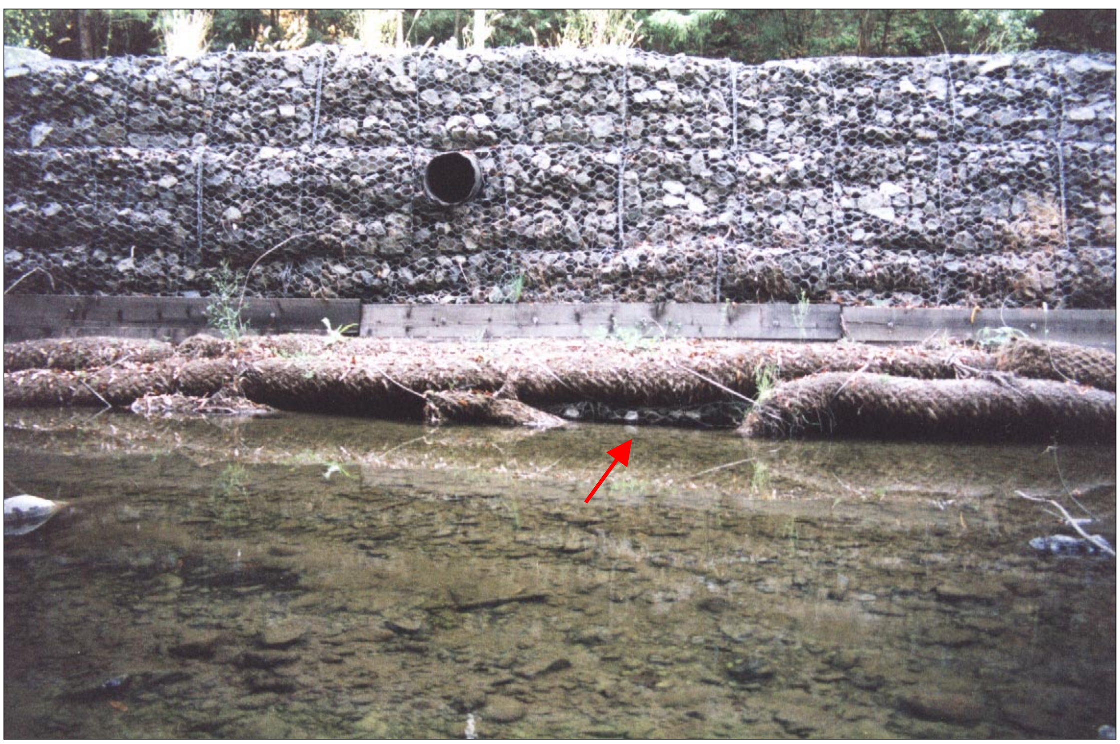


Photo 170. 18-inch diameter culvert is about 90 feet from beginning of 236-foot (72 m) long wall.
Base flow (left to right) on 2 Aug 2000.
Toe scour mat (arrow) visible, fiber rolls in front of mat scoured and washed away.

Site 14 San Gregorio Creek 04-SM-84 post mile 7.2

Photos 171, 172, and 173 looking downstream. Visualize impinging flow just upstream and under bridge.

Photo 171. Thalweg on right side of creek, about 100 feet from gabion wall, 2 Aug 2000.
Rocks (oval) placed randomly in summer of 2000. Right bank scoured, roots exposed, trees leaning.
Plywood, silt fence, straw bale barrier of root wad project at left.

Photo 172. About 25 feet from start of wall, 20 Dec 2000. Flagging at drift (line) high stage in 1st wet season.

Photo 173. Thalweg at left, near start of wall, 20 Dec 2000. Creek was 7' deep at flagging (line).
Several fiber rolls were washed away by storm runoff. Some vegetation on remaining fiber rolls.

Photo 174.
At impinging zone, upstream and under privately-owned bridge. Fiber rolls and bed scoured during 1st wet season.

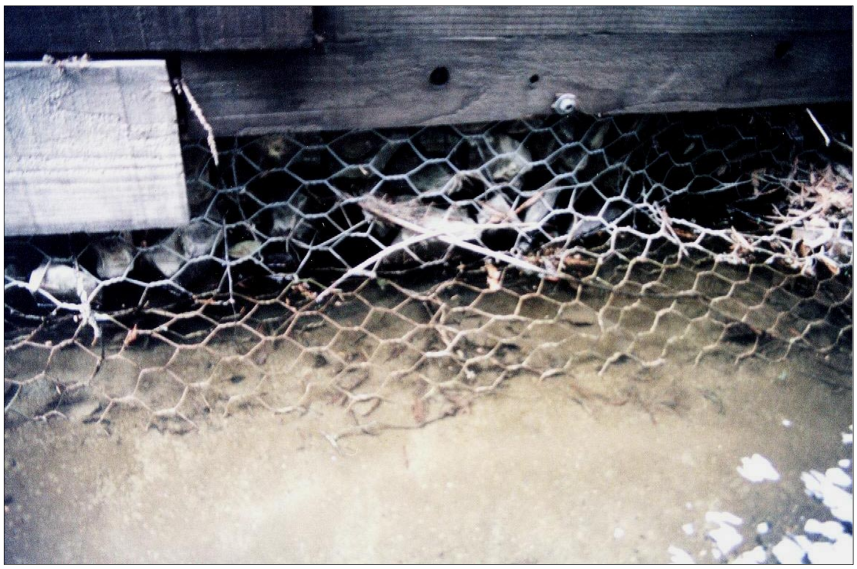


Photo 175. Bottom half of abrasion board missing. Bottom boards installed about 1-foot too high.

Photo 176. About 0.5-foot (indicated by 1st joint of folding ruler) of gabion rock-fill either settled, or it was too small and was scoured through mesh during storm runoff. Brown tint is silt on submerged PVC, not rust.

4. CONCLUSIONS

GENERAL CONCLUSIONS

Corrosion and abrasion are natural effects that decreased the service-life of gabion facilities and/or test panels. An end of gabion service-life is loss of function, and typical functions may be preventing channel erosion or retaining soil of road slopes. Where rock-fall broke wires, there was no loss of function. Determining acceptable performance requires periodic inspections. Where gabions will be considered, designers may be able to reasonably estimate where they may perform well, and where they may not last very long. In our field study, we affirmed that wire strength depends on local exposures at sites, and wire condition is an indicator of the gabion performance and service-life. We have a limited set of tensile strength, soil, and water data, and a photographic log of 14 field sites. We conclude that there is enough information, which was collected over a long enough time, to generally recommend where gabions may and may not serve their function, (perform OK), and where they may and may not last very long (service-life).

At the 14 field sites, for 2 to 16 wet seasons, we monitored 8 gabion products of 2 mesh styles : double twisted hexagonal and welded square grid. Low carbon steel wires had coatings of zinc, zinc and polyvinyl chloride (PVC), or aluminum. At some sites, broken wires and further damage to gabion baskets was gradual, after several years of exposure to combinations of natural effects. At other sites, rock impacts broke wires instantly in single, isolated events. Some local exposures were more severe than others. For example, moist air is a relatively mild exposure for wires, as contrasted to soil saturated with saline water, a very severe exposure. Wire damage and failures related directly to local exposures, and not necessarily to the geometric configurations of gabions themselves. Siting gabions in relation to exposures and immediate surroundings was significant for either good performance or shortened service-life. The status and exposure times of test panels and gabion facilities is in Table 3A in Chapter 3.

Visual inspection was effective for recognizing corrosion and other effects. We compared unexposed (control) BEFORE wires to wires AFTER exposure. Measuring wire diameters or feeling wires was effective for estimating the remaining steel. A confirming measure of wire performance is tensile testing. Tensile testing wires BEFORE and AFTER exposure, was useful for quantifying strength loss. Portions of gabions and test panels that had air-only exposure, except during rain or snow storms, showed the least corrosion and also the least tensile strength loss. In air-only exposure, zinc-coated wires became dull, likely zinc carbonate, an early state of corrosion. PVC-coated wires usually performed better than zinc-coated wires in severe, natural exposures. They showed very little to no strength loss for about 13 years, although wires were in early states of corrosion. Because the bond between PVC and the underlying metal broke after cycling through temperature changes (daily or seasonally), a capillary space formed, where electrolyte migrated, and then corrosion started. In continued severe exposures, we expect that PVC-coated wires will continue to corrode, possibly disintegrating within the confined PVC sheath, or expanding and breaking the PVC as corrosion compounds form.

Test panels did not always indicate what happened to gabion facilities, because we placed test panels in easily accessible areas, which, in some cases, received less of a severe exposure than other parts of the structure. There were wire failures and partial gabion facility failures at 4 sites. At one site, wires were cut by vandals, and at the other 3 sites, wires broke by natural effects of severe local exposures, where corrosion, abrasion, and/or corrassion occurred. Corrassion is erosion of corroded compounds in flowing water. Among the data we do not have, is the duration of flow events, and how many of those events actually moved abrasive particles. Instead, we simply counted and reported the number of wet seasons and years of exposure. Without the confining wire mesh, rock-fill was removed from one or several cells of gabion baskets by gravity and/or by hydraulic forces and/or by people. At the other 9 sites where there are gabion facilities, there were no major problems or any pending failures of what was being protected, so the status was referred to as "OK" in Table 3A. At 1 site where there were only test panels, zinc-coated wires disintegrated, and there was no change detected in PVC-coated wires.

Single broken wires did not render gabion facilities useless. Entire structures did not fail immediately from one or even several broken wires. Multiple closed-cell configuration, successive joining of individual gabion baskets, and the basket geometry gave redundancy to some facilities. While some baskets were damaged, redundantly configured facilities still functioned, and failures were gradual. Where we found failed gabions, road slopes and stream banks have not failed, because since the failures occurred, winters (wet seasons) have been mild with no above normal runoff events.

The BEFORE exposure tensile values are a relatively small statistical sample of 38 test values. Wires were taken from gabions that were manufactured during the mid and late 1980's. We did not collect any more tensile data from gabion wire suppliers later in the field study. We conclude that our data set is small, and it may not represent gabion wire that is manufactured now. Our data likely do not represent recent changes that may have occurred in wire manufacturing processes. In addition, some manufacturers now produce gabion wire with galfan coating. Therefore, we did not develop a method, nor do we propose ways, to forecast wire strength loss as a function of time. We can not exactly quantify gabion performance or service-life. Instead, we may generally estimate the performance and service-life of gabions in settings which have some of the similar exposures that we observed and documented.

There were a few cases of apparent gains in the tensile strength of wires, which can be explained by one or more of the following phenomena :

1. strain aging of wire surface, it hardens (in fabrication, wire is drawn through die).
2. slightly larger diameters of AFTER wires as compared to BEFORE wires.
3. different heats of steel (raw material mixes) of test panels and gabion facility wires.
4. data-set for establishing coefficient of variation of BEFORE wires was too small.

Gabion mesh style did not improve or degrade corrosion performance or service-life. For zinc-coated mesh, our data and observations affirm that either style of mesh, twisted or welded, is equally susceptible to corrosion and other effects. For welded mesh, our predecessor laboratory study and this corollary field study showed that breaks did not normally occur at the weld. As documented in the lab study [Racin, reference 6], welds (resistance-welded wires) are at an elevated energy state, and thus, they are locally cathodic, while 3 or more diameters from the weld, the wire is anodic. Wire between welds corroded more than at the welds, and wires usually broke between welds. The twisted zones of twisted mesh appeared to respond similar to welded mesh in the laboratory study, likely because test panels were hung on racks, and they drained freely in the salt-fog box (ASTM B-117). However, in the field, where there was confining soil, electrolyte was held in the space between twists, and corrosion continued beyond the zinc to the underlying wire. Because corrosion-related strength losses were comparable for long-term and similar exposures, we conclude that neither mesh style out-performed the other.

PVC has a smooth and shiny surface when it is newly manufactured. After about 3 to 5 years of exposure to sunlight, PVC photo-degraded, and it became dull and got chalky. Simply described, photons (incident light) displaced chloride ions in surface molecules. Plasticizers may be added to PVC for flexibility. After about 7 years at site 7, the surfaces of sun-exposed PVC coating developed cracks. As plasticizer compounds volatilized, PVC coating shrank and cracked. Among the sites where test panels were submerged in either mud or water, PVC did not become dull, like sun-exposed PVC. Instead, PVC hardened and often discolored by reacting with its surroundings.

SITE-SPECIFIC CONCLUSIONS

A synopsis is presented for each site in a ranked order of "worst-to-least severe exposure", which is somewhat arbitrary. The rank was based on judgment of wire strengths and gabion facility conditions. Continued exposure will likely alter rankings, if and when the sites are re-evaluated in the future. Among the first 6 sites, we documented relatively severe local exposures, where there was loss of function, that is, an end of service-life of portions of gabion facilities. Or there were degraded facilities or wires, where there may soon be loss of function. The 8 remaining sites had progressively less severe to mild exposures, and wire and facility performance is acceptable (OK), so far. We emphasize that the severity of exposure was local, that is, portions of test panels and/or facilities may have received the severe exposure and failed, while the remainder of the facility was still OK. For details, see the various tables, individual site discussions, and photographic logs in Chapter 3.

Site 1. Likely the most severe exposure and rapid corrosion happened at site 1. There were only test panels, which were placed in an intertidal zone. After about 3 years they were covered with a few inches of fine, corrosive soil (bay mud) and zinc-coated wires lost about half their tensile strength. After about 9.5 years, more than half the zinc-coated wires disintegrated in-place and formed various metallic compounds with the surrounding mud. By then (9.5 years), most of the test panels were buried in about 8-inches of bay mud and saturated with saline water.

Site 2. About 50 feet of a 450-foot long gabion wall (zinc-coated mesh) collapsed into Prairie Creek, about 9 years after it was built. Panels facing the creek of the bottom tier of the wall were alternately submerged, then exposed to air, after storm runoff stages dropped. Such intermittently submerged wires corroded, and they were abraded by sediment that was transported during storm flows. With no confining wires on panels that faced the creek, rocks emptied by gravity from the bottom tier of the wall. Then high flow, high velocity storm runoff washed away the rock. The remaining full and unsupported creek-side baskets became top heavy, then by the action of gravity, they rotated and fell into the creek. Test panels were OK because they were higher than oridnary high water, which was about 1-foot above the dry-weather base flow.

Site 13. Gabion mattresses (PVC-coated mesh) failed in the intertidal zone along the beach at Lime Kiln Creek , because wires mostly abraded. There was rust on wires, and we also saw that wires were ground thin, by gravel, sand, and shells. Sediment was mobilized by breaking waves of the Pacific Ocean. PVC of PVC-coated wires had a relatively short service life of about 18-months in this severe, abrasive exposure. Lid wires completely abraded in about 4 years.

Site 5. In a wetland near Clio, mostly stagnant water and fine-grained, saturated soil provided conditions for relatively rapid corrosion. Among zinc-coated wires of either the test panels or the energy dissipater, there was about 25 to 60 percent tensile strength loss after about 10 years. We did not observe corrasion, as at site 2, because of the very low velocities and mostly stagnant conditions. Available upstream sediment is smaller than fine sand.

Site 9. Gabion mattress lids (zinc-coated mesh) on a road slope (of about 1.5 or 2 horizontal to 1 vertical) failed in less than 15 years due to corrasion. Flash floods of Gower Wash transported sands and gravels over the gabions.

Site 12. There was an un-natural failure under an Interstate bridge over Ulatis Creek in Vacaville. About 10 gabion baskets (PVC-coated mesh) were cut with a wire cutting tool, and gabion rock-fill was either completely or partially emptied by vandals.

Among the following sites, easily recognized failures did not occur during the study, although wires may have corroded and were deteriorated.

Site 4. Portions of the zinc-coated gabions that were submerged in flowing water in Mohawk Creek did not visibly corrode and/or abrade. Normal flowrates and velocities were low. While there are gravel and cobble-sized particles in the creek, they appear to have been transported only once during our observation period, likely in the January 1997 events. In stagnant water at the 36-inch culvert inlet invert apron, submerged wires lost about 50 percent tensile strength in 9 years. On the road slope and along the toe of slope, where they were exposed to the atmosphere, and where they were buried in well-drained soil, mattress wires and test panels did not lose any tensile strength or diameter.

Site 7. Near Alder Creek along the Pacific Coast Highway, gabion walls (PVC-coated mesh) were built beyond the wave height and run-up limit of normal daily, high tide waves. Walls are protected by a rocky beach, they were exposed directly to sunlight and wave splash, and during storms they were submerged by above-normal tides and waves. While PVC has delayed and protected the underlying coatings and wire, it was susceptible to photo-degradation by ultraviolet (uv) light of the sun and got chalky and cracked. Rock impacts abraded PVC and often broke wires on the steps of the step-faced wall. Where PVC was nicked, wire corroded and lost about 35 percent of its tensile strength after about 13 years. Mattresses (PVC-coated mesh) under 8-ton riprap were protected from breaking waves and from abrasive particles. Rock shades the mattresses. Zinc-coated test panels lost nearly 15 percent of tensile strength after about 12 years. As reported in mid-May 2001, the Caltrans Willow Springs Maintenance staff said there was one storm during the 2000-2001 wet season, that washed-away riprap and exposed some gabion mattresses along the north RSP (north of Shale Point). Their assessment indicated that the 4 gabion facilities (2 walls and 2 rock revetments) at site 7 are performing "OK" so far, about 16 years after they were built.

Site 11. Gabion check dams (zinc-coated wire) are in good condition. They were exposed for about 2 years. Cholame Creek has soil with a minimum resistivity less than 500 ohm-cm, which is considered corrosive. The creek bottom soil is freely draining sand, and creek flows are ephemeral and intermittent.

Site 14. A gabion retaining wall (PVC-coated wire), partly in an impinging zone of San Gregorio Creek, has wood facia for abrasion protection. The boards are higher than the thalweg elevation. After 1 wet season, some gabion toe-scour mattresses apparently sank. The wall is OK so far.

Site 8. Similar to site 9, this arroyo in Death Valley has the capability of transporting sands, gravels, and cobbles over PVC-coated gabion slope protection. Because the gabions are buried with the native channel materials, they are OK after 4 years.

Site 6. Gabion walls (zinc-coated mesh) are in very good condition after about 11 years. Snowmelt with chlorides from deicing salts drains freely through the surrounding decomposed granitic soil and gabions.

Site 3. Zinc-coated gabion mattress downdrains are in very good condition after about 11 years. Runoff is intermittent and the surrounding soil drains well.

Site 10 is similar to site 3, except the zinc-coated gabion downdrain was exposed for about 12 years.

Some coatings and gabion wire mesh may not last more than 5 years, and others may last much longer. We can speculate about what may happen to certain wire coatings and wires after prolonged exposures, however, we caution readers about using our data to calculate extrapolations of strength loss over time. We emphasize that the following summary of **Wire Coatings, Exposures, and Time Estimates** and the list of **Likely Indicators of Corrosive and Severe Exposures**, are based on about 16 years or less of data and observations.

WIRE COATINGS, EXPOSURES, and TIME ESTIMATES

We present two general categories of exposures. Time estimates are based on data in Chapter 3. "All" means wires with all coatings, "Zn Al" means zinc-coated and aluminum-coated wires, "PVC" means PVC-coated wires. PVC (site 7) that cracked in about 7 years due to ultra-violet light exposure and volatilized plasticizers, did not fit well in either category 1 or 2. We could have put rock-fall in category 1, but there was no loss of function to PVC-coated gabions (site 7), although there were broken wires.

Category 1 exposures were very corrosive or severe, where test panel wires or gabion facilities **did NOT perform well and/or last very long**. The number or range of years indicates that wires lost about half their strength, wires disintegrated or corraded, and/or there was loss of function (end of service-life).

A. salt-water, tidally influenced sites
   1. All beach where ocean waves broke 1.5 to 4 years
   2. Zn Al slough connected to bay and then to ocean, with cyclic rising and falling tide waters, wind-driven surface ripples 3 to 6 years or less

B. Zn Al fresh water, stagnant pools with low dissolved oxygen 10 years

C. Zn Al saturated soils 10 years

D. Zn Al (PVC likely) creeks, streams, arroyos (watercourses in arid regions) with storm runoff that conveyed abrasive soil particles and debris, corrasion (erosion of corroded compounds), cyclic rising and falling water levels 9 to 15 years

E. PVC (All likely) vandalism, urban/suburban sites, wires cut, rock emptied 1 year

Category 2 exposures were mild to moderately corrosive, not very severe, where test panel wires and/or gabion facilities **have performed well** so far, for about 16 years.

A. All wave splash and spray, near-shore fog

B. All fresh water sites with intermittent, channelized storm runoff and/or streams that transport little or no suspended particles greater than 0.074 mm and/or low velocity water with low conductivity and high dissolved oxygen

C. All well-drained soil and/or dry soil conditions

D. All atmosphere

E. All sites where rock-fall impacted and broke gabion wires, baskets not empty

F. PVC OK in category 1 exposures A 2 (slough), B (stagnant pools), C (wet soils)

LIKELY INDICATORS of CORROSIVE and SEVERE EXPOSURES

The following values are rough indicators of soil and water properties, where there were corrosive and severe exposures. Values are not "absolute", and they were based on our results. See table footnotes in Chapter 3 for test methods and/or measuring devices.

1. Soil minimum resistivity less than 1000 ohm-cm
2. Transported soil particle sizes greater than 0.074 mm
3. Saturated soil with about 30 percent or more particles smaller than 0.074 mm
4. Water conductivity greater than 5000 micro-siemans
5. Water salinity greater than 3 percent
6. Stagnant water with dissolved oxygen less than 3 mg/L
7. High energy zones in water, stream velocity greater than 6 fps, breaking waves
8. Cyclic submergence in water (fresh or saline) and air, rising and falling water levels.

5. RECOMMENDATIONS

RE-EVALUATE SITES

In the previous chapter of Conclusions, times estimates in the outline on page 100, **Wire Coatings, Exposures, and Time Estimates**, may be considered as an initial Caltrans data source for defining the performance and service-life of gabion facilities. The limit of our data and observations is about 16 years. Because we do not know exactly how much longer than 16 years a gabion facility may last without repairs or replacement, our first recommendation is that sites 2 through 12 and 14 should be re-visited and re-evaluated in about 3 to 5 years, but no less than 10 years (by 2011). Then the time estimates may be updated.

ADD to KNOWLEDGE

We encourage readers who own and maintain gabion facilities, to share documentation with the author for their facilities which may have lasted longer than 16 years or less. To add to knowledge about gabion performance and service-life, basic information is needed. The information consists of the age of the site, photographs of the facility and local exposures (taken after construction and most recently), any soil and water data, atmospheric conditions, annual rainfall, any hydraulic information (stage, velocity, flow rate, estimated count of high velocity events), and design features that may have been included to reduce the effects of severe exposures. A brief write-up would be helpful, which describes history, maintenance, and an evaluation of performance or the failure mechanism and repair strategy. To contact the author, see Chapter 6, Implementation.

WIRE CONDITION, PERFORMANCE, SERVICE-LIFE

Gabions may be among the materials that are being considered for protecting a channel, for retaining soil of a road slope, or for some other function. When the materials are within specifications, and when gabions are properly designed, sited, assembled, and constructed, then the wires may be considered as the weakest element. We determined that wire damage from corrosion, abrasion, and/or rock impact, depends on local exposures at a site. After wires are broken, rock-fill may be lost by the action of gravity and/or hydraulic forces, and/or people in the event of vandalism. When rock-fill is gone, the gabion loses its function, the features they were protecting become susceptible to further damage and/or failure, and the gabion is considered to have spent part or all of its service-life. So, selecting the appropriate wire coating may help to assure reasonably expected performance and service-life.

SELECT WIRE COATING

We offer some basic recommendations for the designer to select a wire coating for a gabion facility at a proposed site. When we state that the designer should collect data, we are using "designer" in a general sense. Within Caltrans or other agencies, field data may be collected by specialty units. Our intent is not to define or reassign duties, but to clarify the data need. We emphasize that the Caltrans designer selects wire coating, not the contractor. Considering only material costs, if the contractor selected wire coating, they would likely always select zinc, because it is less expensive than PVC-coated mesh.

A question the designer must answer is, will the gabion facility be temporary or permanent ? If the designer has no idea of how long temporary and permanent may be, then based on our data, we suggest some arbitrary definitions. Temporary means wires may last about 10 years or less, and permanent means wires may last about 16 years or longer. We emphasize these are arbitrary definitions, and we do not know exactly how long a gabion facility may last without repairs or replacement.

A field-review of the proposed site is required. The designer should try to visualize the local exposures and final configuration of gabions, and other likely products and materials. The outline on page 100 (**Wire Coatings, Exposures, and Time Estimates**) may be used to categorize local exposures, that is, which exposures at the site may be severe, or which exposures may be mild to moderately corrosive. The outline may also be used to select the wire coating, either zinc or PVC-coated. On Caltrans contracts, as of May 2001, there are 2 choices for gabion wire mesh coatings : zinc or PVC, where PVC really means zinc and PVC. For example, suppose a gabion gravity wall is proposed at the boundary of a wetland. Categories 1B and 1C are likely exposures. Reading the rest of the outline, category 2F indicates that PVC-coated mesh was OK for categories 1B and 1C.

At this point, we may state that PVC is the wire coating. However, before finally deciding on PVC, soil and/or water samples should be collected and analyzed, then compared to data we collected at our test sites. Some soil tests may already have been done, and results may have been documented in a materials or geotechnical report. Using the list on page 100 of **Likely Indicators of Corrosive and Severe Exposures** as a guide, the designer can determine values that apply at the proposed site. Some conditions that produce the local exposures may not exist until the facility is built. Where tests can not be done, exposures may have to be assumed or visualized. For example, at site 5, an energy dissipater at a culvert outlet was built in a constructed wetland. Initially there was no wetland and no stagnant water to test. The designer may have visualized that wetlands have stagnant water, therefore indicators 3 and 6 would be likely, and PVC would be the preferred choice of wire coating.

When ordering tests, it is important that samples are collected as close to the final proposed facility location and exposures as possible. By experience and judgment, if samples were too distant to relate to the exposures, then additional tests may be justified.

Suggested soil tests and California test methods are in the footnote of Table 3B on page 22. When ordering CA test 643, minimum soil resistivity, require the determination of pH, sulfates, and chlorides. Soil particle size distributions are determined by CA test methods 202 and 203, and the results should be plotted as in Figures 3-1 through 3-4. As suggested in the Table 3B column heading and footnote, field identify and also name the soil according to the Unified Soil Classification System. Suggested instantaneous water measurements are in Table 3C column headings on page 27. The source of water should be identified : stagnant or flowing, high or low velocity, continual or ephemeral, tidal, wave action, etc. When no instruments are available, some data may be deduced by general association, that is, indicators 1, 3, 6, and 8 are likely for a wetland, or indicators 1, 4, and 5 are likely in saline waters of oceans, bays, and sloughs connected to bays.

In addition to soil and water data, the proposed gabion facility should be built in a manner where the effects of severe local exposures can be limited. Information about likely local exposures and other nearby physical features, may alter the siting and design details. The designer should try to visualize how any nearby physical features and effects may influence the facility throughout its service-life. If some possible effect was not already visualized during the field review, then getting a second opinion from a local engineer or from one of the local maintenance people may be enlightening.

To limit the effects of severe exposures, the designer may consider adding features to the gabion design. For example, at San Gregorio Creek (site 14), the designer recognized that the gabion wall was being built on the outside bend of a creek, a category 1D exposure. The gravity wall was first designed with a typical safety factor. Then a damage scenario was visualized, that is, several outside cells were emptied, after exposures to high energy / high velocity flows and abrasion. The safety factor fell below what the designer wanted. So, to keep the safety factor in an acceptable range, additional gabions (cells) were added to the cross-section of the wall. Additionally, a less expensive, and expendable feature was added to the wall, wood facia. Boards (2x12's) were attached near the bottom of the wall, as a visual cue for abrasion and exposure to recent high energy / high velocity events.

Another example of limiting the severe local exposure was at site 8, where gabion road slope protection was very likely to be exposed to abrasive particles during flash floods. The National Park Service required Caltrans to bury the gabions for aesthetics, that is, they wanted park visitors to see native desert materials alongside the road. That requirement is a benefit for the performance and service-life of the gabions. The additional native materials delay the abrasive attack on the wires. When the gabions are uncovered, it indicates the relative severity of recent flash floods. This is a simple visual cue to maintain the gabion facility by replacing the native cover.

After field-reviewing the site, visualizing likely local exposures, collecting and analyzing soil and water test results, and considering any additional design features and siting requirements, the designer may finally select the wire coating.

CALTRANS SSP’s and STANDARD PLANS

The Caltrans Standard Special Provisions (SSP’s) were written to distinguish between the two available corrosion coatings. The Caltrans gabion SSP’s encourage competition by allowing either mesh style, which is normally selected by the contractor. On Caltrans contracts, we recommend using the SSP’s in Appendix A : 72-300 Gabions (PVC-coated) is for PVC-coated mesh, and 72-305 (Gabions) is for zinc-coated mesh. Appendix A has copies of the specifications and also standard plans D100A and D100B with instructions for downloading electronic copies from the Caltrans Office Engineer world wide web site.

Designers should incorporate the SSP’s and Standard Plans on Caltrans contracts. For contract compliance testing of gabion materials, the published values and tables in the SSP’s may be used to guide the acceptance or rejection of gabion materials. Construction inspectors should refer to the standard plans and SSP’s to assure proper construction of gabions, especially the method of making basket-to-basket joints. Examples of out-of-specification joints are seen on page 82, photos 141 through 143. Acceptable joints are described in the SSP's and clarified in the "Notes" on Standard Plan Sheet D100B.

Basic requirements in the Caltrans gabion SSP's are similar to ASTM gabion specifications, however, they differ in some respects. The ASTM specifications have far more tests than a user group like Caltrans would ever request. Only a few manufacturers developed the ASTM gabion specifications. There is a separate ASTM specification for twisted mesh and one for welded mesh. Either mesh style is comparable to the other, as Caltrans demonstrated in full-scale load tests [Hoover, reference 1], [Nelson, reference 2], and [Hoover, reference 3]. There was no substantial difference in the flexibility response of 1-foot high mattresses for either mesh style in a cantilever pull-out test. Nor was there any substantial difference in the deflection measurements of unsupported 6-foot spans, for 3-foot high x 3-foot wide x 12-foot long gabions with an additional 4000 pound load. Our corrosion field study found no substantial difference in corrosion and abrasion effects between the two mesh styles.

The Caltrans SSP's have been critiqued as being lengthy. That was intentional. We believe there is enough information to guide relatively inexperienced contractors, as well as construction inspectors, in the proper assembly and gabion construction techniques, which may help to produce a quality facility. The Caltrans SSP's and the standard plans went through numerous iterations of usage, review, and redrafting, before they were finally adopted. Input and numerous review comments were received from several competing gabion manufacturers, resident construction engineers and inspectors, contractors, and knowledgeable and interested units within Caltrans. We believe the Caltrans SSP's and standard plans represent a collective "best effort" by all who contributed.

MAINTENANCE : INSPECTION and REPAIR of GABION FACILITIES

As part of the experimental design, when broken wires and/or empty gabion cells were detected, we observed and photographed the structure annually or bi-annually and after severe events. For gabions that were no longer functioning, we reported that information to local Caltrans District staff : maintenance, hydraulic, and/or geotechnical units. After some further inspection and investigation, repairs were proposed and some were done, while others were pending as of May 2001.

Doing periodic site inspections and a keeping a log of photographic images are recommended. By staying informed about the performance of a gabion facility, loss of function may be prevented. And by responding in a timely manner to complete any needed repairs, failure may be prevented of the features that are being protected. For "routine inspections" by Caltrans maintenance, based on our data, a reasonable inspection frequency for gabion facilities may be about 3 to 5 years, and after severe events.

Again, as part of the experimental design, our repair strategy was to immediately repair incidental damage due to collecting wire samples. That is, when we cut wires from full-scale gabion facilities, we immediately repaired the cut-out zone with new mesh. Ideally, any simple repairs may be done by maintenance crews, if such work were funded, scheduled, and if repair materials were available. However, because of staffing, funding, and other higher priority work, it is not typical for Caltrans maintenance staff to repair gabions on a piece-meal basis, that is, fixing a few wires or baskets at a time. Instead, the damaged facility may be reported to a responsible unit in the Caltrans District or region.

The responsible unit may order a detailed damage assessment, which may help identify the risks of delaying repairs. Repair plans should be formulated and carried out when function has been lost, that is, when the loss of the gabions will likely lead to further damage of road slopes or channels. Repairs may range from fastening new sections of mesh that overlap broken wires, re-filling empty cells with rock and replacing entire panels, placing concrete or grout to fill empty baskets, capping or encapsulating parts of the structure with concrete, or replacing gabions with different materials. The responsible unit may recommend whether the repairs should be done by Caltrans or by contract.

SITE-SPECIFIC RECOMMENDATIONS

For **sites 2** and **13**, specific recommendations for repairs were already presented in the discussions on pages 38 and 83, respectively.

At **site 9** the failed gabion mattresses should be re-evaluated within the next 3 years. The failed baskets should be counted, so an estimate can be prepared for ordering gabion repair materials. An alternative material to gabions may be RSP-fabric and native rock, since abrasion is the dominant exposure, and not seeing the wire mesh is a requirement.

At **site 12** a bridge inspection report for bridge 23 0052 (left and right bridges) indicated that the vandalized baskets would be repaired by contract. A follow-up inspection report is expected after the repairs are completed.

At **site 1** there was no gabion facility or any other slope protection, however the incidental slope erosion just beyond the culvert wingwalls due to rising and falling tides should be further investigated. If slope protection is required, a possible material to consider is 1-foot high PVC-coated gabion mattresses.

At **site 5** if the zinc-coated wires of the wetland energy dissipater baskets completely corrode, the rock-fill may still be present. This site should be re-evaluated within the next 3 years. As a minimum, the culvert hydraulics should be reviewed to confirm whether the outlet velocity is a large enough to displace the standard gabion rock-fill (4-inch minimum to 12-inch maximum) in the near-zero-gradient wetland channel.

At **site 8**, as implied in the conclusions, the gabions may continue to last for as long as they remain buried, and not exposed to attack by abrasive particles during flash floods or severe wind storms. So, with permission from the National Park Service, it is recommended that any exposed gabions be re-buried with the native soils.

At **site 11**, after the new Cholame Creek bridges are built, one of the options being explored is to leave the buried gabion check dams in-place. There is another nearby bridge upstream, and it would likely benefit from the stabilized creekbed elevation, due to the check dams. Because soil tests indicated likely severe exposures, (very corrosive = minimum soil resistivity less than 500 ohm-cm, abrasive = SP, silty sand), the gabions should be uncovered and inspected. If gabion wire is still present, and if some mesh and fasteners were brought along as repair materials, then a sample of wire could be collected for possible tensile testing.

We recommend that site re-evaluations be done in the following suggested order in about 5 years, or after severe events : **site 4, 7, 14, 6, 3, and 10**.

OTHER WIRE COATINGS - GALFAN, ALUMINUM

Assuming there are no ongoing studies, for any new (to Caltrans) wire coatings, we recommend both laboratory and field studies. Such tests may reveal the limitations of new materials and/or wire fabricating processes. Contact the author (see next Chapter, Implementation) for recommendations on experimental design, sample size, test methods, and procedures. Generally, develop and follow an experimental design similar to what is documented in this report and in [Racin, reference 6].

We have no specific recommendations for galfan (Zn-5 Al-MM) or other coatings at this time. If galfan will become a routinely produced material, then future testing should be done on gabion wires that are coated with galfan.

The Al-coated test panels that we received and tested, were specially manufactured for the field study, and we observed them for about 6 years. Gabion manufacturers have not routinely manufactured Al-coated gabion mesh, and we never received draft material specifications for Al-coated gabion wire. Therefore, we have no recommendations for using aluminum-coated wire as gabion mesh.

CALTRANS HIGHWAY DESIGN MANUAL

This report may be used to guide updates in various topics which discuss gabions in the **Caltrans Highway Design Manual**, Chapter 870 or other chapters.

GABIONS and FISH

While not mentioned in the text of this report, at **site 2** several gabion weirs were proposed to be built across Prairie Creek, to help control the creek gradient in the shortened channel, due to the gabion wall. They were deleted from the contract by change order. Generally, the California Department of Fish and Game (CA DFG) recommends not using gabions as weirs in streams and rivers, mainly because they are very susceptible to abrasion, and we concur with that view.

Where there are salmonid, other biota, habitat, and fish passage concerns, it is recommended that research and/or documentation be requested from CA DFG or others, to address any issues about using gabion walls, bank protection, and slope protection along creeks, streams, and/or rivers.

6. IMPLEMENTATION

PAPERLESS REPORT

The report was intended for distribution as a paperless report. The entire report is in **pdf** (portable document file) format, and it is readable with Adobe Acrobat ® Reader, version 4 or higher. A paper report (hard-copy) is available for loan at the Caltrans Headquarters Library, 1120 N Street, in Sacramento, CA. A CD-ROM may be obtained from the author or from the Office of Pavement Research Management, Technology Transfer Branch in the Division of New Technology and Research.

The hyperlink http://www.dot.ca.gov/hq/oppd/hydrology/gabion.htm (single left-click or you may be able to right-click for opening options) should connect you to the Caltrans Internet web site, where there are instructions with hyperlinks for downloading the entire paperless report and some general guidance. If you connect via the Caltrans DESIGN DIVISION web site http://www.dot.ca.gov/hq/oppd , click on "Manuals & Guidance", then "Other Publications", then the report title Gabion Mesh Corrosion.

The report may also be ordered from the National Technical Information Service (NTIS). See box 18 on the Technical Report Documentation (Abstract) page for the NTIS phone number and address. When ordering from NTIS, cite the government accession number (PB2001-102895) in addition to the report title, subtitle, and authors.

PRINTED COPY

Printed (hard-copy) reports are not routinely available from Caltrans. The reader should probably first electronically view and then print selected pages. We recommend a color printer for best results, because there are more than 176 color images. On black and white printers, select the gray-scale option. Most photographic images were scanned at 200 dpi (dots per inch), so setting the resolution beyond 600 dpi does not improve the result. If your print menu has advanced options, a few tips are :

1. If your printer does not have Arial True Type font, then under "font selection" before you click the Print button, you may be able to select the "Download as soft font" option. Or Helvetica seems to be an acceptable font substitution for Arial.
2. If the copy will be 3-hole punched, and if you are printing from Adobe Acrobat ® Reader 4.0, before you click the Print button, look at the print menu options. Check the "Fit to page" box and then print the image. It will be 95 percent of full size, and the 3-hole punch will not remove much text or photo image.
3. Similar to 2, for actual image size, only check the box labeled "Print as image".

CONTACT the AUTHOR

If you know of a failure or maintenance and re-construction activities at any of the gabion sites mentioned in this report, then after contacting the local Caltrans District Office staff, please contact the principal author. Also, contact the author, if you own and maintain gabions and can add to knowledge of gabion performance and service-life.

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APPENDIX A - STANDARD SPECIAL PROVISIONS (SSP's)

The following instructions were tested and worked OK in May 2001. They should give you access to Caltrans Office Engineer Internet sites, where you may download the specifications (Standard Special Provisions - SSP's) for PVC-coated and zinc-coated gabions.

After you download the **.doc** files, open them in Microsoft ® (MS) Word. To see the edit instructions for designers/specification writers, turn-on the hidden text option. In MS Word, along the top menu, select "Tools", then "Options", then click on the VIEW tab, then check the HIDDEN TEXT box, then click OK.

1. a. Connect to the Internet.

   b. To get (72-300), the SSP for PVC-coated gabions, click on the following hyperlink :
http://www.dot.ca.gov/hq/esc/oe/specifications/SSP's/99-SSPs/Sec_10/61-75/72-300_A02-10-00.doc

For your own copy of the file, choose the "save as" option from the Microsoft ® (MS) Word menu.

   c. To get (72-305), the SSP for zinc-coated gabions, click on the following hyperlink :
http://www.dot.ca.gov/hq/esc/oe/specifications/SSP's/99-SSPs/Sec_10/61-75/72-305_A02-10-00.doc

2. If the above hyperlinks did not work, then try the following instructions.

a. Connect to the Internet and then click on or type all of the following address and hit return :
http://www.dot.ca.gov/hq/esc/oe/
You should get connected to a site labeled
Office Engineer California Department of Transportation

b. Click on the next several links : (none are actually linked from this document) :
Construction Standards
Standard Specifications and Special Provisions Information
Standard Special Provisions (SSP's)
99-SSP's/
Sec 10/
61-75/

c. Scroll down until you locate the following files.
72-300 A02-10-00.DOC 24-Mar-00 14:58 45K (not linked from this document)
72-305 A02-10-00.DOC 24-Mar-00 14:58 42K (not linked from this document)

d. The first file (72-300) is the SSP for PVC-coated gabions, and the second file (72-305) is the SSP for zinc-coated gabions. To get a copy of the file, (while connected to the Internet) click on the filename, then choose the "save it to disk" option and follow the screen prompts.

{ XE "72-300_A02-10-00" }

USE WHEN PVC COATING OF WIRE REQUIRED

Use with Standard Plans D100A & B.

Add SSP 72-150, except for downdrain applications of gabions. Contact Office of State Highway Drainage Design for general assistance and woven tape fabric specifications for downdrains.

Gabions used as retaining walls must be designed by the Division of Structure Design.

10-1.1__ GABIONS (POLYVINYL CHLORIDE COATED)

Gabions shall be constructed as shown on the plans and in conformance with these special provisions.

2

Gabions shall consist of wire mesh, cubical-celled or mattress-styled baskets that are filled on the project site with hard, durable rock. The individual wires shall have a polyvinyl chloride (PVC) coating.

3. The plans must show cross section which specifies dimensions of width and height. Length and width limits must be shown in plan view.

Standard gabion sizes and the overall plan and profile dimensions of the gabion structures shall be as shown on the plans. Each standard gabion size shall be divided into one meter long cells by diaphragm panels. The width, height or length of the standard gabions shall not vary more than 5 percent from the dimensions specified in these special provisions or as shown on the plans.

4

Empty gabion baskets shall be assembled individually and joined successively. Individual gabion mesh panels (base, front, ends, back, diaphragms, and lid) and successive gabions shall be assembled so that the strength and flexibility along the joints is comparable to a single panel.

5

MATERIALS

All materials for the gabions and gabion assembly shall conform to the provisions in these special provisions. Each shipment of gabion baskets to the project site shall be accompanied by a Certificate of Compliance conforming to the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

6

Mesh

At the Contractor's option, either twisted mesh or welded mesh shall be used, in conformance with Table 1 and Table 2 herein. For each standard gabion size, the same mesh style shall be used for the base, front, ends, back, diaphragms, and lid panels. Individual wires of either the twisted-mesh style or the welded-mesh style shall conform to the definitions and requirements in ASTM Designation: A641/A641 M.

7. Designer may edit wire gage to specific requirement if necessary, within the range of wire sizes given in the Tables below.

Mattress-style gabion baskets that are 0.3–m and 0.5–m high shall be manufactured from either 11-gage (3.05 mm) welded mesh or 12-gage (2.69 mm) twisted mesh. Cubical-celled gabion baskets that are one meter high by one meter wide shall be fabricated from 12-gage (2.69 mm) twisted mesh or welded mesh gages between 11–gage (3.05 mm) and 9–gage (3.76 mm), inclusive.

Table 1

CUBICAL-CELLED FACILITIES	
USA WIRE GAGE	MESH STYLE
12	Twisted Mesh
11 Min to 9 Max	Welded Mesh

Table 2

MATTRESS-STYLE FACILITIES	
USA WIRE GAGE	MESH STYLE
12	Twisted Mesh
11	Welded Mesh

GABION MESH MATERIAL PROPERTIES

Characteristic	Test Designation	Requirement
Minimum tensile strength	ASTM A370	410 MPa
Wire Size Wire Diameter (Minimum) Galvanizing, Zinc	USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	12 2.69 mm 2.59 mm 230 g/m^2
Wire Size Wire Diameter (Minimum) Galvanizing, Zinc	USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	11 3.05 mm 2.95 mm 240 g/m^2
Wire Size Wire Diameter (Minimum) Galvanizing, Zinc	USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	9 3.76 mm 3.66 mm 270 g/m^2

8

Twisted-mesh wires shall form a uniform hexagonal pattern and shall be formed with a nonraveling twist. The area of the hexagonal opening shall not exceed the dimensions shown on the plans. Twisted-mesh gabion panels shall be manufactured from 12-gage (2.69 mm) wires with 10-gage (3.43 mm) selvage wires.

9

Welded-mesh wires shall form a grid pattern as shown on the plans. Welds shall be made by resistance welding. Welds and panels shall conform to the requirements in ASTM Designation: A185, except weld shears shall be 2.7 kN for 11-gage (3.05 mm) wires and 3.6 kN for 9-gage (3.76 mm) wires. Resistance welding after coating the wire with zinc will be acceptable if there are no large splashes, flakes or flashes of zinc at the weld.

10

Polyvinyl Chloride (PVC) Coating

External coating shall consist of a nonconductive material, primarily polyvinyl chloride (PVC). Mesh wire, standard tie wires, standard spiral binders, internal connecting wires, preformed stiffeners, and selvage wire shall be coated with the PVC material after the zinc coating is applied in conformance with the manufacturer's specifications.

11

The PVC coating shall be evaluated by infrared spectral scan. The scan must closely match those of tested known acceptable products already on file at the Transportation Laboratory.

12

The minimum thickness of PVC which covers the wire shall be 0.38-mm, measured radially at any cross-section transverse to the wire length.

13

The PVC coating shall be complete by visual inspection. There shall be no nicks, cuts, holidays or abraded areas in the PVC coating of the mesh. Minor cuts, nicks, and other minor imperfections due to manufacturing, will be permitted along selvage-wrapped edges of twisted mesh. PVC will not be required to coat the ends of either style of mesh where the PVC has been trimmed along wire or panel edges during the normal manufacturing process.

14

PVC coating shall be resistant to degradation by ultraviolet (UV) radiation. A suitable, UV-resistant additive shall be blended with the PVC. This additive shall be identified on the Certificate of Compliance.

15 Gray is typically used, but black, brown, tan, etc. can be special ordered.

The color of the PVC shall be ________. The color shall be resistant to fading when exposed to natural sunlight.

16

Joints

Standard tie wire and standard spiral binder shall conform to the definitions and requirements in ASTM Designation: A641/A641 M and shall conform to the following provisions:

Minimum Tensile Strength	ASTM A370	410 MPa
Tie Wire Wire Size (Minimum) Wire Diameter (Minimum) Zinc Coating	 USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	 13.5 2.19 mm 2.09 mm 220 g/m^2
Spirals Wire Size (Maximum) Wire Diameter (Minimum) Zinc Coating	 USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	 9 3.76 mm 3.66 mm 270 g/m^2

17

Spiral binders shall have a 75 mm to 85 mm separation between continuous, successive loops.

18

Alternative fasteners shall have the configurations, wire diameters, and other dimensions shown on the plans. Alternative fasteners shall conform to the definitions and requirements in ASTM Designation: A313/A313 M for "Stainless Steel Spring Wire" and shall be Tensile Type 302, Class 1.

19

Internal Connecting Wire

Internal connecting wires shall be 13.5-gage (2.19 mm) minimum. Each wire shall conform to the minimum requirements for standard tie wire in these special provisions and shall be installed in conformance with the provisions in these special provisions and as shown on the plans. Alternatively, at the Contractor's option, preformed stiffeners may be substituted for internal connecting wires. Preformed stiffener wire shall meet the requirements specified for standard tie wire and shall be installed in conformance with these special provisions and the manufacturer's recommendations.

20. Use SSP 72-150.

Rock Slope Protection Fabric

Rock slope protection fabric for use with gabions shall conform to the provisions in Section 88–1.04, "Rock Slope Protection Fabric," of the Standard Specifications and these special provisions.

21. Delete this para if gabion downdrains are not included in project. Contact the Office of State Highway Drainage Design for woven tape special provisions.

Where gabions are used for downdrains, woven tape fabric shall be used in place of the rock slope protection fabric. The woven tape fabric shall conform to the requirements in ASTM Designation: D 4491, with a maximum permittivity of 0.10 per second.

22

Rock

Rock for filling gabions, which are greater than or equal to 0.5-m in height, shall vary in size and shall conform to the following:

Screen Size (mm)	Percentage Passing
305	100
102	0-5

23

Rock for filling gabions, which are equal to 0.3-m in height, shall vary in size and shall conform to the following:

Screen Size (mm)	Percentage Passing
203	100
102	0-5

24

Rock shall conform to the material provisions for rock slope protection in Section 72-2.02, "Materials," of the Standard Specifications.

25

The minimum unit mass of a rock-filled gabion shall be 1750 kg/m^3. Verification of the 1750 kg/m^3 shall be performed when ordered by the Engineer. Verification shall be performed on the smallest standard gabion size to be used on the project. The rock supplied for the project shall be used for verification. Filling shall be done using the same method intended for actual construction. The mass of a rock-filled gabion shall be determined using available certified scales. The volume for calculating the unit mass shall be determined on the theoretical volume of the standard gabion which is rock-filled and weighed.

26

GRADING, EXCAVATION AND BACKFILL

Areas where gabions are to be placed shall be constructed to the lines and grades shown on the plans and as determined by the Engineer. Excavation or backfill for achieving the required grades shall conform to the provisions for structure excavation and backfill in Section 19, "Earthwork," of the Standard Specifications.

27

ROCK SLOPE PROTECTION FABRIC PLACEMENT

Rock slope protection fabric shall be placed in conformance with the provisions in Section 72-2.025, “Rock Slope Protection Fabric” of the Standard Specifications. Rock slope protection fabric shall be placed on the subgrade, backslope, and sides of excavations. If earth fill is to be placed over the gabions, rock slope protection fabric shall be placed on top of the gabions, before placing the earth fill.

28

CONSTRUCTION

Gabions shall be assembled individually as empty units. Each gabion shall be manufactured with the necessary panels, properly spaced and secured, so that the panels can be rotated into position at the construction site with no additional tying of the rotation joint. The panels and diaphragms shall be rotated into position and joined along the vertical edges.

29

For twisted mesh, the joint shall be constructed using alternating double and single half hitches (locked loops) of 13.5-gage (2.19 mm) standard tie wire at 100-mm nominal spacing. Joints shall not be constructed with simple spiraling (looping without locking) of the standard tie wires.

30

When standard tie wire is used as a joint connector for welded mesh, the joint shall be constructed using alternating double and single half hitches (locked loops) in every mesh opening along the joint. When 9-gage (3.76 mm) spiral binders are used, the spiral shall be placed so that the spiral binder passes through each mesh opening along the joint. Both ends of all 9-gage (3.76 mm) spiral binders shall be crimped to secure the spiral in place.

31

Temporary fasteners may be used to hold panels wherever gabion-to-gabion joints will be constructed. Temporary fasteners may remain in place.

32

At the Contractor’s option, interlocking fasteners or overlapping fasteners may be used for assembly of either the twisted-mesh or welded-mesh gabions. A fastener shall be placed in each mesh opening along the joint (a minimum of 10 fasteners per meter).

33

ASSEMBLY OF SUCCESSIVE GABION BASKETS (GABION-TO-GABION JOINTS)

Gabion baskets shall be set in place. Individually constructed gabion baskets shall then be joined successively to the next gabion baskets with 13.5-gage (2.19 mm) tie wire or 9-gage (3.76 mm) standard spiral binder before filling the basket with rock. The 13.5-gage (2.19 mm) standard tie wire or 9-gage (3.76 mm) standard spiral binder shall secure, in one pass, all selvage or end wires of the panels of all adjacent baskets along the joint.

34

When forming successive gabion-to-gabion joints with alternative fasteners, there shall be one alternative fastener in each mesh opening. The alternative fastener shall contain and secure all the wires along the joint.

35

Gabion baskets shall be joined along the front, back, and ends, including the tops and bottoms of the adjacent gabions.

36

ASSEMBLY OF MULTIPLE LAYERED GABIONS

Multi-layered gabion configurations shall be stepped and staggered as shown on the plans or as designated by the Engineer.

37

When constructing multi-layered gabion configurations, each layer of gabions shall be joined to the underlying layer along the front, back, and ends.

38

ASSEMBLY OF SHEAR KEY GABIONS

Shear key gabions, or counterforts, shall be spaced as shown on the plans. Shear key gabions shall be tied to adjacent gabions in the manner specified for "Assembly of Successive Gabion Baskets (Gabion-to-Gabion Joints)" of these special provisions.

39

ASSEMBLY OF TRANSITIONAL GABIONS

To match the geometry of the planned gabion configuration, or to meet specific conditions, panels shall be folded, cut and fastened as shown on the plans or as directed by the Engineer.

40

FILLING WITH ROCK

Before filling each gabion basket with rock, all kinks and folds in the wire fabric shall be straightened and all successive gabions shall be properly aligned.

41

Rock shall be placed in the baskets to provide proper alignment, avoid bulges in the wire mesh, and provide a minimum of voids. All exposed rock surfaces shall have a smooth and neat appearance. Sharp rock edges shall not project through the wire mesh.

42

Internal connecting wires or preformed stiffeners shall be used to produce a flat, smooth external surface, when constructing with 0.5-m or one meter high gabions. If the Engineer determines that there is excessive bulging or dimpling of the outside panels, the unit shall be reconstructed at the Contractor’s expense.

43

When filling one meter high gabions, rock shall be placed in 2 nominal 0.33-m layers to allow placement of the 13.5-gage (2.19 mm) internal connecting wires. The wires shall be fastened as shown on the plans. Alternatively, preformed stiffeners may be installed at the one-third points in conformance with the recommendations of the manufacturer, to produce a smooth external surface.

44

When filling 0.5-m high gabions, one nominal 0.25-m layer of rock shall be placed to allow placement of a set of internal connecting wires or preformed stiffeners. The configuration of wires shall be similar to those used on the one meter high gabions, except there shall be only one set of internal connecting wires instead of the 2 sets of internal connecting wires or preformed stiffeners.

45

The last layer of rock shall slightly overfill the gabion baskets so that the lid will rest on rock when the lid is closed.

46

CLOSURE OF LIDS

Lids shall be tied along the front, ends, and diaphragms in conformance with the provisions in "Assembly of Successive Gabion Baskets (Gabion-to-Gabion Joints)" of these special provisions.

47

MEASUREMENT

Gabions will be measured by the cubic meter as determined from the dimensions shown on the plans or the dimensions directed by the Engineer and gabions placed in excess of these dimensions will not be paid for.

48

PAYMENT

The contract price paid per cubic meter for gabion shall include full compensation for furnishing all labor, materials (including gabion baskets, rock and rock slope protection fabric), tools, equipment, and incidentals, and for doing all the work involved in constructing gabions, complete, in place, including excavation and backfill, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

{ XE "72-305_A02-10-00" }

USE WHEN PVC COATING OF WIRE IS "NOT" REQUIRED

Use with Standard Plans D100A & B.

Add SSP 72-150, except for downdrain applications of gabions. Contact Office of State Highway Drainage Design for general assistance and woven tape fabric specifications for downdrains.

Gabions used as retaining walls must be designed by the Division of Structure Design.

10-1.1__ GABIONS

Gabions shall be constructed as shown on the plans and in conformance with these special provisions.

2

Gabions shall consist of wire mesh, cubical-celled or mattress-styled baskets that are filled on the project site with hard, durable rock.

3. The plans must show cross section which specifies dimensions of width and height. Length and width limits must be shown in plan view.

Standard gabion sizes and the overall plan and profile dimensions of the gabion structures shall be as shown on the plans. Each standard gabion size shall be divided into one meter long cells by diaphragm panels. The width, height or length of the standard gabions shall not vary more than 5 percent from the dimensions specified in these special provisions or as shown on the plans.

4

Empty gabion baskets shall be assembled individually and joined successively. Individual gabion mesh panels (base, front, ends, back, diaphragms, and lid) and successive gabions shall be assembled so that the strength and flexibility along the joints is comparable to a single panel.

5

MATERIALS

All materials for the gabions and gabion assembly shall conform to the provisions in these special provisions. Each shipment of gabion baskets to the project site shall be accompanied by a Certificate of Compliance conforming to the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

6

Mesh

At the Contractor's option, either twisted mesh or welded mesh shall be used, in conformance with Table 1 and Table 2 herein. For each standard gabion size, the same mesh style shall be used for the base, front, ends, back, diaphragms, and lid panels. Individual wires of either the twisted-mesh style or the welded-mesh style shall conform to the definitions and requirements in ASTM Designation: A641/A641 M.

7. Designer may edit wire gage to specific requirement if necessary, within the range of wire sizes given in the Tables below.

Mattress-style gabion baskets that are 0.3–m and 0.5–m high shall be manufactured from either 11-gage (3.05 mm) welded mesh or twisted mesh. Cubical-celled gabion baskets that are one meter high by one meter wide shall be fabricated from 11-gage (3.05 mm) twisted mesh or welded mesh gages between 11–gage (3.05 mm) and 9–gage (3.76 mm), inclusive.

Table 1

CUBICAL-CELLED FACILITIES	
USA WIRE GAGE	MESH STYLE
11	Twisted Mesh
11 Min to 9 Max	Welded Mesh

Table 2

MATTRESS-STYLE FACILITIES	
USA WIRE GAGE	MESH STYLE
11	Twisted Mesh
11	Welded Mesh

GABION MESH MATERIAL PROPERTIES

Characteristic	Test Designation	Requirement
Minimum tensile strength	ASTM A370	410 MPa
Wire Size Wire Diameter (Minimum) Galvanizing, Zinc	USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	11 3.05 mm 2.95 mm 240 g/m^2
Wire Size Wire Diameter (Minimum) Galvanizing, Zinc	USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	9 3.76 mm 3.66 mm 270 g/m^2

8

Twisted-mesh wires shall form a uniform hexagonal pattern and shall be formed with a nonraveling twist. The area of the hexagonal opening shall not exceed the dimensions shown on the plans. Twisted-mesh gabion panels shall be manufactured from 11-gage (3.05 mm) wires with 9-gage (3.76 mm) selvage wires.

9

Welded-mesh wires shall form a grid pattern as shown on the plans. Welds shall be made by resistance welding. Welds and panels shall conform to the requirements in ASTM Designation: A185, except weld shears shall be 2.7 kN for 11-gage (3.05 mm) wires and 3.6 kN for 9-gage (3.76 mm) wires. Resistance welding after coating the wire with zinc will be acceptable if there are no large splashes, flakes or flashes of zinc at the weld.

10

Joints

Standard tie wire and standard spiral binder shall conform to the definitions and requirements in ASTM Designation: A641/A641 M and shall conform to the following provisions:

Minimum Tensile Strength	ASTM A370	410 MPa
Tie Wire Wire Size (Minimum) Wire Diameter (Minimum) Zinc Coating	 USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	 13.5 2.19 mm 2.09 mm 220 g/m^2
Spirals Wire Size (Maximum) Wire Diameter (Minimum) Zinc Coating	 USA Steel Wire Gage ASTM A641/A641 M ASTM A641/A641 M ASTM A641/A641 M, Class 3 and ASTM A90 / A90M	 9 3.76 mm 3.66 mm 270 g/m^2

11

Spiral binders shall have a 75 mm to 85 mm separation between continuous, successive loops.

12

Alternative fasteners shall have the configurations, wire diameters, and other dimensions shown on the plans. Alternative fasteners shall conform to the definitions and requirements in ASTM Designation: A764 for "Metallic Coated Carbon Steel Wire, Coated at Size and Drawn to Size for Mechanical Springs." Interlocking fasteners shall conform to Tensile Requirement Class I, Finish 2 and shall have a Class 3 zinc coating, Overlapping fasteners shall conform to Tensile Requirement Class II, Finish 1 and shall have a Class 3 zinc coating.

13

Internal Connecting Wire

Internal connecting wires shall be 13.5-gage (2.19 mm) minimum. Each wire shall conform to the minimum requirements for standard tie wire in these special provisions and shall be installed in conformance with the provisions in these special provisions and as shown on the plans. Alternatively, at the Contractor's option, preformed stiffeners may be substituted for internal connecting wires. Preformed stiffener wire shall meet the requirements specified for standard tie wire and shall be installed in conformance with these special provisions and the manufacturer's recommendations.

14. Use SSP 72-150.

Rock Slope Protection Fabric

Rock slope protection fabric for use with gabions shall conform to the provisions in Section 88–1.04, "Rock Slope Protection Fabric," of the Standard Specifications and these special provisions.

15. Delete this para if gabion downdrains are not included in project. Contact the Office of State Highway Drainage Design for woven tape special provisions.

Where gabions are used for downdrains, woven tape fabric shall be used in place of the rock slope protection fabric. The woven tape fabric shall conform to the requirements in ASTM Designation: D 4491, with a maximum permittivity of 0.10 per second.

16

Rock

Rock for filling gabions, which are greater than or equal to 0.5-m in height, shall vary in size and shall conform to the following:

Screen Size (mm)	Percentage Passing
305 102	100 0-5

17

Rock for filling gabions, which are equal to 0.3-m in height, shall vary in size and shall conform to the following:

Screen Size (mm)	Percent age Passing
203 102	100 0-5

18

Rock shall conform to the material provisions for rock slope protection in Section 72-2.02, "Materials," of the Standard Specifications.

19

The minimum unit mass of a rock-filled gabion shall be 1750 kg/m^3. Verification of the 1750 kg/m^3 shall be performed when ordered by the Engineer. Verification shall be performed on the smallest standard gabion size to be used on the project. The rock supplied for the project shall be used for verification. Filling shall be done using the same method intended for actual construction. The mass of a rock-filled gabion shall be determined using available certified scales. The volume for calculating the unit mass shall be determined on the theoretical volume of the standard gabion which is rock-filled and weighed.

20

GRADING, EXCAVATION AND BACKFILL

Areas where gabions are to be placed shall be constructed to the lines and grades shown on the plans and as determined by the Engineer. Excavation or backfill for achieving the required grades shall conform to the provisions for structure excavation and backfill in Section 19, "Earthwork," of the Standard Specifications.

21

ROCK SLOPE PROTECTION FABRIC PLACEMENT

Rock slope protection fabric shall be placed in conformance with the provisions in Section 72-2.025, “Rock Slope Protection Fabric” of the Standard Specifications. Rock slope protection fabric shall be placed on the subgrade, backslope, and sides of excavations. If earth fill is to be placed over the gabions, rock slope protection fabric shall be placed on top of the gabions, before placing the earth fill.

22

CONSTRUCTION

Gabions shall be assembled individually as empty units. Each gabion shall be manufactured with the necessary panels, properly spaced and secured, so that the panels can be rotated into position at the construction site with no additional tying of the rotation joint. The panels and diaphragms shall be rotated into position and joined along the vertical edges.

23

For twisted mesh, the joint shall be constructed using alternating double and single half hitches (locked loops) of 13.5-gage (2.19 mm) standard tie wire at 100-mm nominal spacing. Joints shall not be constructed with simple spiraling (looping without locking) of the standard tie wires.

24

When standard tie wire is used as a joint connector for welded mesh, the joint shall be constructed using alternating double and single half hitches (locked loops) in every mesh opening along the joint. When 9-gage (3.76 mm) spiral binders are used, the spiral shall be placed so that the spiral binder passes through each mesh opening along the joint. Both ends of all 9-gage (3.76 mm) spiral binders shall be crimped to secure the spiral in place.

25

Temporary fasteners may be used to hold panels wherever gabion-to-gabion joints will be constructed. Temporary fasteners may remain in place.

26

At the Contractor’s option, interlocking fasteners or overlapping fasteners may be used for assembly of either the twisted-mesh or welded-mesh gabions. A fastener shall be placed in each mesh opening along the joint (a minimum of 10 fasteners per meter).

27

ASSEMBLY OF SUCCESSIVE GABION BASKETS (GABION-TO-GABION JOINTS)

Gabion baskets shall be set in place. Individually constructed gabion baskets shall then be joined successively to the next gabion baskets with 13.5-gage (2.19 mm) tie wire or 9-gage (3.76 mm) standard spiral binder before filling the basket with rock. The 13.5-gage (2.19 mm) standard tie wire or 9-gage (3.76 mm) standard spiral binder shall secure, in one pass, all selvage or end wires of the panels of all adjacent baskets along the joint.

28

When forming successive gabion-to-gabion joints with alternative fasteners, there shall be one alternative fastener in each mesh opening. The alternative fastener shall contain and secure all the wires along the joint.

29

Gabion baskets shall be joined along the front, back, and ends, including the tops and bottoms of the adjacent gabions.

30

ASSEMBLY OF MULTIPLE LAYERED GABIONS

Multi-layered gabion configurations shall be stepped and staggered as shown on the plans or as designated by the Engineer.

31

When constructing multi-layered gabion configurations, each layer of gabions shall be joined to the underlying layer along the front, back, and ends.

32

ASSEMBLY OF SHEAR KEY GABIONS

Shear key gabions, or counterforts, shall be spaced as shown on the plans. Shear key gabions shall be tied to adjacent gabions in the manner specified for "Assembly of Successive Gabion Baskets (Gabion-to-Gabion Joints)" of these special provisions.

33

ASSEMBLY OF TRANSITIONAL GABIONS

To match the geometry of the planned gabion configuration, or to meet specific conditions, panels shall be folded, cut and fastened as shown on the plans or as directed by the Engineer.

34

FILLING WITH ROCK

Before filling each gabion basket with rock, all kinks and folds in the wire fabric shall be straightened and all successive gabions shall be properly aligned.

35

Rock shall be placed in the baskets to provide proper alignment, avoid bulges in the wire mesh, and provide a minimum of voids. All exposed rock surfaces shall have a smooth and neat appearance. Sharp rock edges shall not project through the wire mesh.

36

Internal connecting wires or preformed stiffeners shall be used to produce a flat, smooth external surface, when constructing with 0.5-m or one meter high gabions. If the Engineer determines that there is excessive bulging or dimpling of the outside panels, the unit shall be reconstructed at the Contractor's expense.

37

When filling one meter high gabions, rock shall be placed in 3 nominal 0.33-m layers to allow placement of the 13.5-gage (2.19 mm) internal connecting wires. The wires shall be fastened as shown on the plans. Alternatively, preformed stiffeners may be installed at the one-third points in conformance with the recommendations of the manufacturer, to produce a smooth external surface.

38

When filling 0.5-m high gabions, 2 nominal 0.25-m layers of rock shall be placed to allow placement of a set of internal connecting wires or preformed stiffeners. The configuration of wires shall be similar to those used on the one meter high gabions, except there shall be only one set of internal connecting wires instead of the 2 sets of internal connecting wires or preformed stiffeners.

39

The last layer of rock shall slightly overfill the gabion baskets so that the lid will rest on rock when the lid is closed.

40

CLOSURE OF LIDS

Lids shall be tied along the front, ends, and diaphragms in conformance with the provisions in "Assembly of Successive Gabion Baskets (Gabion-to-Gabion Joints)" of these special provisions.

41

MEASUREMENT

Gabions will be measured by the cubic meter as determined from the dimensions shown on the plans or the dimensions directed by the Engineer and gabions placed in excess of these dimensions will not be paid for.

42

PAYMENT

The contract price paid per cubic meter for gabion shall include full compensation for furnishing all labor, materials (including gabion baskets, rock and rock slope protection fabric), tools, equipment, and incidentals, and for doing all the work involved in constructing gabions, complete, in place, including excavation and backfill, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

APPENDIX A - STANDARD PLANS

For determining quantities on gabion jobs, project engineers/designers will need a PLAN view that shows the layout and limits of the proposed gabion facility and typical CROSS-SECTION (s). In addition, **both gabion standard plans D100A and D100B must be included in contract plans**. When labeling baskets on layouts or cross-sections, use the letter codes of standard gabion sizes, as tabled on sheet D100A. The following instructions were tested and worked OK in May 2001. They should give you access to the Caltrans Office Engineer (OE) Internet world wide web site, and you should be able to get both of the standard plans. Since the OE web site and Standard Plans Book will be updated, these instructions will become obsolete. If you search future Standard Plans books by the Standard Plan Number and/or name, you are likely to find them.

1. Connect to the Internet, then click on or type the following address and hit enter :
http://www.dot.ca.gov/hq/esc/oe/project_plans/HTM/99_plans_disclaim_met.htm
You should get connected to the California Department of Transportation Office Engineer site
1995 & 1999 Metric Standard Plans - Special Notices And Updates

2. To download files in **.dxf** or **.dgn** format, then click-on the second link
Individual 1999 Metric Standard Plans Sheets (in .dxf, .dgn, and .pdf formats)
(not linked from this document) which connects you to the **1999 Standard Plans - (metric)** site.
See 4 below if you just want to download and view the plans or print a copy to your local printer.

   Scroll down through the Table of Contents and under the heading of **General Road Work (Drainage)** and you should find the following links (neither is linked from this document)
Gabion Basket Details No. 1 Plan No. D100A (.dxf) (.dgn)) (click to view)
Gabion Basket Details No. 2 Plan No. D100B (.dxf) (.dgn)) (click to view)
Put your pointer directly on the file format you want to download, **.dxf** or **.dgn** and click on it. Follow the screen prompts and download a compressed (**.zip**) file. If you select **click to view** you will download an Adobe Acrobat ® **.pdf** (portable document file) image.

3. On the **1995 & 1999 Metric Standard Plans - Special Notices and Updates** site, if you clicked on the first link Entire 1999 Standard Plans Book (in .pdf format) then you will have started to download the entire book of metric standard plans in **.pdf** format, which is about 58.5 megabytes, and that may be OK if you have a fast connection, otherwise go back to 2 above.

   If you acquire the entire file, then to view the gabion standard plans, type the page number in the Adobe Acrobat ® page number zone, usually seen at the lower left of the screen.
   For plan D100A the Adobe Acrobat ® page number is 156 of 360 (actual page 143),
   For plan D100B the Adobe Acrobat ® page number is 157 of 360 (actual page 144).

4. To simply download **.pdf** files which you can view and print to your local printer, then click on or type the following hot-linked addresses and hit enter.

   A. for plan D100A
http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_metric_99/viewable_pdf/d100a.pdf

   B. for plan D100B
http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_metric_99/viewable_pdf/d100b.pdf

DIST	COUNTY	ROUTE	KILOMETER POST TOTAL PROJECT	SHEET NO.	TOTAL SHEETS

Caltrans Metric

REGISTERED CIVIL ENGINEER

July 1, 1999
PLANS APPROVAL DATE

REGISTERED PROFESSIONAL ENGINEER
Glenn DeCou
No. C34547
Exp. 9-30-99
CIVIL
STATE OF CALIFORNIA

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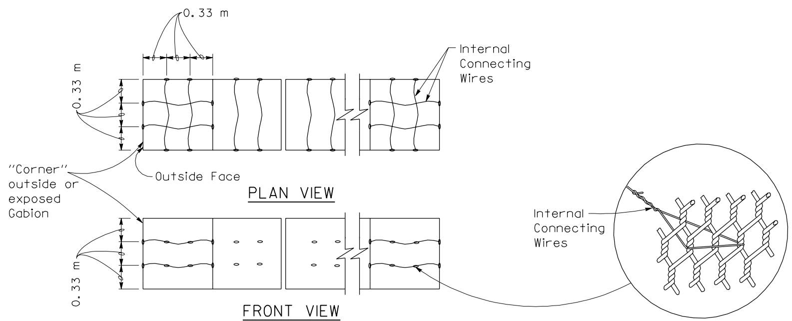
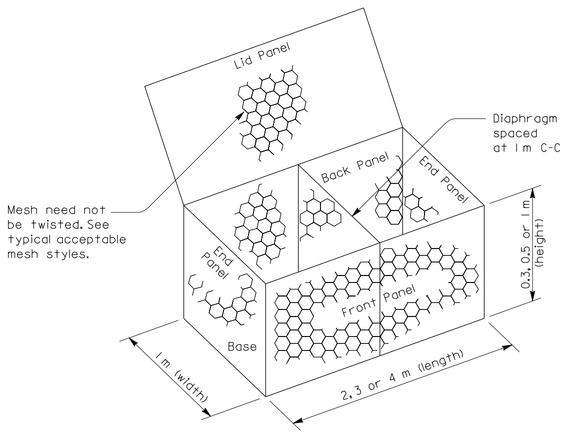


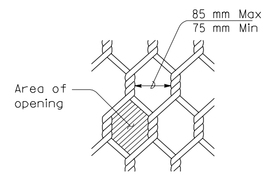
13.5-GAGE INTERNAL CONNECTING WIRES

STANDARD GABION SIZES					
LETTER CODE	LENGTH	WIDTH	HEIGHT	NUMBER OF DIAPHRAGMS	VOLUME
	m				m^3
A	2	1	1	1	2.0
B	3	1	1	2	3.0
C	4	1	1	3	4.0
D	2	1	0.5	1	1.0
E	3	1	0.5	2	1.5
F	4	1	0.5	3	2.0
G	2	1	0.3	1	0.6
H	3	1	0.3	2	0.9
I	4	1	0.3	3	1.2

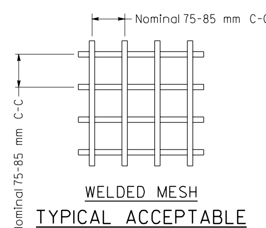


TYPICAL GABION BASKET

Note: Area of opening not to exceed 6650 mm^2.



TWISTED MESH



WELDED MESH

TYPICAL ACCEPTABLE MESH STYLES

NOTES

1. Internal connecting wire (13.5-gage) to be installed across width of interior Gabions and across width and length of end Gabions.
2. Internal connecting wire and Gabion mesh shall be galvanized.
3. Internal connecting wires required on all gabions 1 m high.
4. Preformed stiffeners (11-gage or 9-gage) are an acceptable alternative to internal connecting wires. Install them as recommended by manufacturer or as directed by the Engineer at 1/3 points.
5. Place rock in end Gabion cell first, and continue by filling interior Gabion cells.
6. For Gabion dimensions, refer to table "Standard Gabion Sizes".

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

GABION BASKET DETAILS NO. 1

NO SCALE

ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE SHOWN

D100A

DIST	COUNTY	ROUTE	KILOMETER POST TOTAL PROJECT	SHEET NO.	TOTAL SHEETS

Caltrans Metric

REGISTERED CIVIL ENGINEER

July 1, 1999
PLANS APPROVAL DATE

REGISTERED PROFESSIONAL ENGINEER Glenn DeCou No. C34547 Exp. 9-30-99 CIVIL STATE OF CALIFORNIA

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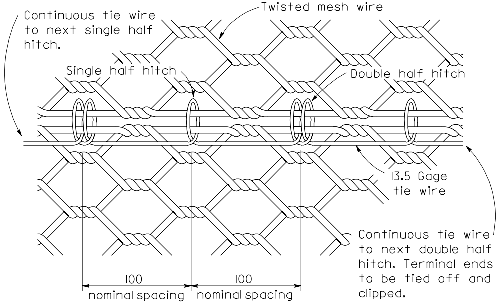
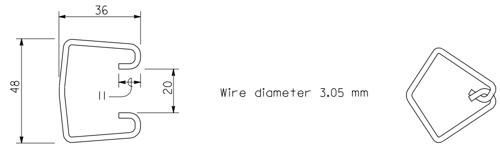
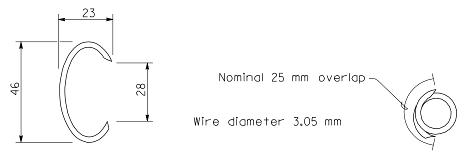


STANDARD TIE WIRE DETAIL

Alternating single and double half hitches (locked loops)
(See Note 2)



INTERLOCKING FASTENER



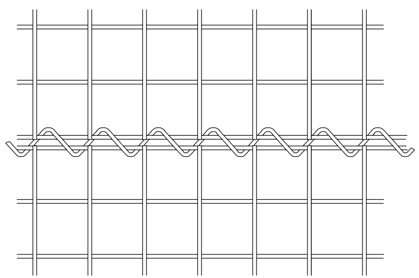
OVERLAPPING FASTENER

ALTERNATIVE GABION JOINT MATERIAL FASTENERS

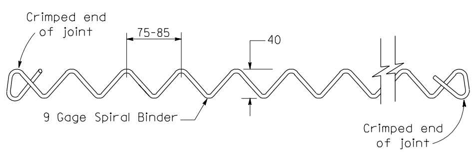
(Fastener dimensions nominal)
(See Notes 3 and 4)

NOTES

1. A joint connection must be made where any panel edge meets another panel. This includes adjacent gabion baskets, individual panels within a basket, diaphragm edges, etc.
2. Standard tie wire may be used as a joint connector for either twisted or welded mesh. Spiral binder is to be used with welded mesh only.
3. When alternative Gabion joint material fasteners are used, one fastener must be installed in each mesh opening (10 fasteners minimum per meter). Mesh openings are counted along one of the panels at the joint.
4. When alternative Gabion joint material fasteners are not capable of enclosing all wires along a joint, especially at Basket-To-Basket Joints, either standard tie wire or sprial binder, as applicable, must be used.

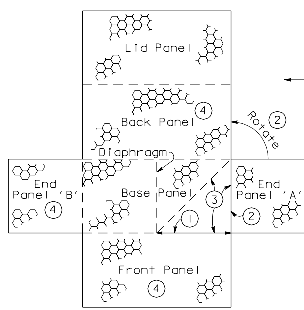


SPIRAL BINDER LACING



STANDARD SPIRAL BINDER

(See Note 2)



FLAT LAYOUT OF GABION BASKET

To Assemble Transitional Gabion Basket:

Step (1) Cut mesh along joint between Front Panel and Base Panel.

Step (2) Unfasten End Panel 'A' from Base Panel and rotate End Panel 'A'. Fasten End Panel Panel 'A' to Back Panel.

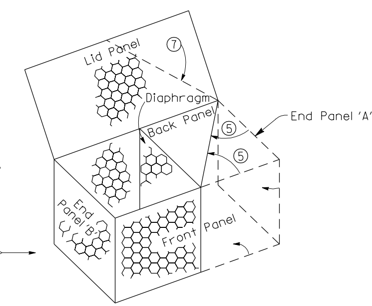
Step (3) Fold the cut portion of the Base Panel into upright position along diagonal from the diaphragm to the corner of the Back Panel.

Step (4) Fold the Back Panel, Front Panel and End Panel 'B' into upright positions. Fasten End Panel 'B' to the Back Panel and the Front Panel.

Step (5) Rotate End Panel 'A' and the cut portion of the Front Panel inward against the upturned portion of the Base Panel. Fasten along the overlapped portion of the Front Panel and End Panel 'A'. Fasten the overlapped portion of the Front Panel and End Panel 'A' to the folded upright portion of the Base Panel along the diagonal (described in Step 3).

Step (6) Fill the Transitional Gabion Basket with rock as per specifications.

Step (7) Close lid and fold over corner of Lid Panel. Fasten along Lid Panel edges.



ASSEMBLED TRANSITIONAL GABION BASKET

TRANSITIONAL GABION BASKET

(For 2 m: 3 m: or 4 m gabion)

1999 STD. PLAN D100B

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

GABION BASKET DETAILS NO. 2

NO SCALE

ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE SHOWN

D100B

Appendix B

Ultimate Tensile Force Data and Descriptive Statistics
Individual Wires of Gabion Mesh BEFORE Exposure

Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Product 7
839	1495	1212	786	604	817	677
867	1501	1221	849	610	786	598
831	1496	1194	750	621	773	686
827	1494	1206	775	600	809	601
863	1491	1196	822	706	778	642
840	1500	1217	846	618	828	598
830	1511	1259	782	614	815	637
831	1507	1157	764	617	781	682
838	1505	1183	768	624	763	646
820	1500	1265	840	704	809	637
860	1511	1224	772	618	820	700
831	1506	1156	769	641	759	633
827	1502	1212	774	634	761	641
829	1513	1242	861	615	829	634
828	1497	1155	842	615	775	646
857	1501	1228	879	604	777	681
854	1493	1262	772	598	798	694
826	1490	1100	774	606	729	607
845	1497	1142	779	637	792	617
824	1503	1144	790	606	730	603
844	1504	1265	787	602	778	597
833	1495	1137	842	594	821	612
861	1502	1130	816	574	730	596
856	1498	1238	900	625	810	678
853	1498	1242	843	599	827	593
832	1506	1242	916	600	807	602
852	1493	1188	862	681	823	614
831	1500	1131	824	578	797	595
844	1494	1252	895	595	778	633
822	1493	1222	777	626	830	691
948	1470	1052	776	626	799	651
942	1513	1208	750	618	825	642
945	1476	1061	899	616	821	597
945	1486	1060	874	706	748	680
949	1494	1026	847	643	824	618
967	1311	1092	787	615	796	695
972	1492	1229	898	601	776	689
957	1315	1291	750	607	781	604

38 tensile tests per product.

POUNDS FORCE is the unit of ultimate tensile force and also of the mean, standard error, median, mode, standard deviation,
range, minimum, maximum, and sum.

Appendix B

Ultimate Tensile Force Data and Descriptive Statistics
Individual Wires of Gabion Mesh BEFORE Exposure

Product 1 zinc-coated 11-gage welded	
Mean	863.7
Standard Error	7.9
Median	844
Mode	831
Standard Deviation	48.6
Sample Variance	2363.7
Kurtosis	0.059
Skewness	1.290
Range	152
Minimum	820
Maximum	972
Sum	32820
Count	38
CV	5.63

POUNDS FORCE is the unit of ultimate tensile force and also of the mean, standard error, median, mode, standard deviation, range, minimum, maximum, and sum.

Coefficient of Variation is dimensionless and is expressed as a percent.
CV = standard deviation / mean * 100

Product 2 zinc-coated 9-gage welded	
Mean	1488.2
Standard Error	6.9
Median	1497.5
Mode	1494
Standard Deviation	42.8
Sample Variance	1830.1
Kurtosis	14.676
Skewness	-3.889
Range	202
Minimum	1311
Maximum	1513
Sum	56553
Count	38
CV	2.88

Product 3 PVC-coated 10.5-gage welded	
Mean	1185.3
Standard Error	10.9
Median	1207
Mode	1242
Standard Deviation	67.4
Sample Variance	4547.7
Kurtosis	-0.264
Skewness	-0.740
Range	265
Minimum	1026
Maximum	1291
Sum	45041
Count	38
CV	5.69

Appendix B

Ultimate Tensile Force Data and Descriptive Statistics
Individual Wires of Gabion Mesh BEFORE Exposure

Product 4 zinc-coated 11-gage twisted	
Mean	816.8
Standard Error	8.1
Median	803
Mode	750
Standard Deviation	50.0
Sample Variance	2495.6
Kurtosis	-1.129
Skewness	0.431
Range	166
Minimum	750
Maximum	916
Sum	31037
Count	38
CV	6.12

Product 6 zinc-coated 11-gage twisted	
Mean	792.1
Standard Error	4.8
Median	796.5
Mode	778
Standard Deviation	29.3
Sample Variance	858.4
Kurtosis	-0.417
Skewness	-0.602
Range	101
Minimum	729
Maximum	830
Sum	30100
Count	38
CV	3.70

Product 5 PVC-coated 12-gage twisted	
Mean	621.0
Standard Error	5.1
Median	615
Mode	618
Standard Deviation	31.2
Sample Variance	973.3
Kurtosis	2.651
Skewness	1.637
Range	132
Minimum	574
Maximum	706
Sum	23598
Count	38
CV	5.02

Product 7 PVC-coated 12-gage twisted	
Mean	638.1
Standard Error	5.8
Median	635.5
Mode	598
Standard Deviation	35.8
Sample Variance	1278.9
Kurtosis	-1.316
Skewness	0.360
Range	107
Minimum	593
Maximum	700
Sum	24247
Count	38
CV	5.61

POUNDS FORCE is unit of ultimate tensile force and also of the mean, standard error, median, mode, standard deviation, range, minimum, maximum, and sum.

Coefficient of Variation is dimensionless and is expressed as a percent.
CV = standard deviation / mean * 100

Appendix C-1

Ultimate Tensile Force Data   Individual Wires of Gabion Mesh
AFTER 2.85 Years of Exposure at Site 1 White Slough 01-Hum-101 pm 70 Northbound

Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Product 7
637	529	1270	187	634	508	687
625	801	1149	98	714	558	601
686	727	1137	149	623	643	667
814	565	1266	377	600	673	693
669	666	1273	566	717	659	625
684	1086	1140	99	606	647	605
729	1119	1248	115	717	560	636
762	1039	1134	244	632	670	642
625	1166	1133	257	624	636	623
627	1164	1271	422	624	708	623
619	882	1270	837	643	668	678
768	1124	1259	488	623	510	697
589	919	1270	691	634	687	634
707	1252	1271	790	609	623	597
719	1256	1135	777	622	456	602
703	803	1275	723	596	542	674
658	1061	1236	719	607	498	639
764	753	1253	710	598	757	631
667	1230	1127	712	633	769	590
652	1041	1258	681	602	649	681
677	1100	1242	577	615	735	591
733	1187	1138	684	604	602	675
616	1277	1227	635	593	571	653
652	1193	1128	618	609	692	650
661	1080	1149	686	593	678	683
718	1199	1249	610	628	592	603
681	1226	1260	579	633	687	641
658	1072	1146	678	688	650	653
615	1128	1117	582	632	628	646
722	1085	1271	743	605	560	644

30 tensile tests per product.

POUNDS FORCE is the unit of ultimate tensile force.

Typical descriptive statistics are not shown,
instead see Table 3E-1, report page 30.

Appendix C-2

Ultimate Tensile Force Data   Individual Wires of Gabion Mesh

AFTER Various Exposures (see Table 3A)

Lot	Dist-Co-Rte-PM	Sub-location	Product No.	Force	Unit
5191	05-Mon-1-8.1	Test panel North Wall	5	658.4	lbf
5192	05-Mon-1-8.1	Test panel North Wall	5	616.8	lbf
5193	05-Mon-1-8.1	Test panel North Wall	5	639.4	lbf
5194	05-Mon-1-8.1	Test panel North Wall	5	696.6	lbf
4191	05-SLO-46-48.3	Check Dam	4	873.4	lbf
4192	05-SLO-46-48.3	Check Dam	4	894.8	lbf
4193	05-SLO-46-48.3	Check Dam	4	915.9	lbf
4194	05-SLO-46-48.3	Check Dam	4	874.0	lbf
1191	03-ED-50-63.9	Test Panel	1	870.7	lbf
1192	03-ED-50-63.9	Test Panel	1	919.6	lbf
1193	03-ED-50-63.9	Test Panel	1	836.0	lbf
1194	03-ED-50-63.9	Test Panel	1	831.3	lbf
1195	03-ED-50-63.9	Wall Lid Panel	1	1104.3	lbf
1196	03-ED-50-63.9	Wall Lid Panel	1	1112.1	lbf
1197	03-ED-50-63.9	Wall Lid Panel	1	1106.5	lbf
1198	03-ED-50-63.9	Wall Lid Panel	1	1105.8	lbf
2191	03-ED-50-63.9	Test Panel	2	1513.5	lbf
2192	03-ED-50-63.9	Test Panel	2	1487.4	lbf
2193	03-ED-50-63.9	Test Panel	2	1507.6	lbf
2194	03-ED-50-63.9	Test Panel	2	1501.6	lbf
3191	03-ED-50-63.9	Test panel	3	1119.5	lbf
3192	03-ED-50-63.9	Test panel	3	1224.9	lbf
3193	03-ED-50-63.9	Test panel	3	1200.6	lbf
3194	03-ED-50-63.9	Test panel	3	1217.9	lbf
4191	03-ED-50-63.9	Test panel	4	832.6	lbf
4192	03-ED-50-63.9	Test panel	4	874.6	lbf
4193	03-ED-50-63.9	Test panel	4	782.7	lbf
4194	03-ED-50-63.9	Test panel	4	847.8	lbf
5191	03-ED-50-63.9	Test panel	5	656.0	lbf
5192	03-ED-50-63.9	Test panel	5	631.8	lbf
5193	03-ED-50-63.9	Test panel	5	631.5	lbf
5194	03-ED-50-63.9	Test panel	5	613.7	lbf
6191	03-ED-50-63.9	Test panel	6	817.0	lbf
6192	03-ED-50-63.9	Test panel	6	837.4	lbf
6193	03-ED-50-63.9	Test panel	6	722.8	lbf
6194	03-ED-50-63.9	Test panel	6	761.7	lbf
8191	03-ED-50-63.9	Test panel	8	729.7	lbf
8192	03-ED-50-63.9	Test panel	8	709.1	lbf
8193	03-ED-50-63.9	Test panel	8	687.7	lbf
8194	03-ED-50-63.9	Test panel	8	686.0	lbf
7191	03-ED-50-63.9	Test panel	7	652.6	lbf
7192	03-ED-50-63.9	Test panel	7	684.1	lbf
7193	03-ED-50-63.9	Test panel	7	640.5	lbf
7194	03-ED-50-63.9	Test panel	7	651.4	lbf

Appendix C-2

Ultimate Tensile Force Data   Individual Wires of Gabion Mesh

AFTER Various Exposures (see Table 3A)

Lot	Dist-Co-Rte-PM	Sub-location	Product No.	Force	Unit
1591	02-PLU-89-4.6	Test panel	1	690.1	lbf
1592	02-PLU-89-4.6	Test panel	1	673.1	lbf
1593	02-PLU-89-4.6	Test panel	1	697.1	lbf
1594	02-PLU-89-4.6	Test panel	1	613.1	lbf
2591	02-PLU-89-4.6	Test panel	2	1043.0	lbf
2592	02-PLU-89-4.6	Test panel	2	1055.0	lbf
2593	02-PLU-89-4.6	Test panel	2	1051.4	lbf
2594	02-PLU-89-4.6	Test panel	2	1145.1	lbf
3591	02-PLU-89-4.6	Test panel	3	1062.0	lbf
3592	02-PLU-89-4.6	Test panel	3	1037.1	lbf
3593	02-PLU-89-4.6	Test panel	3	1197.0	lbf
3594	02-PLU-89-4.6	Test panel	3	1109.0	lbf
4591	02-PLU-89-4.6	Test panel	4	392.7	lbf
4592	02-PLU-89-4.6	Test panel	4	179.3	lbf
4593	02-PLU-89-4.6	Test panel	4	362.1	lbf
4594	02-PLU-89-4.6	Test panel	4	572.1	lbf
5591	02-PLU-89-4.6	Test panel	5	610.8	lbf
5592	02-PLU-89-4.6	Test panel	5	613.3	lbf
5593	02-PLU-89-4.6	Test panel	5	620.0	lbf
5594	02-PLU-89-4.6	Test panel	5	619.1	lbf
6591	02-PLU-89-4.6	Test panel	6	316.4	lbf
6592	02-PLU-89-4.6	Test panel	6	291.2	lbf
6593	02-PLU-89-4.6	Test panel	6	256.7	lbf
6594	02-PLU-89-4.6	Test panel	6	357.3	lbf
7591	02-PLU-89-4.6	Test panel	7	688.0	lbf
7592	02-PLU-89-4.6	Test panel	7	635.4	lbf
7593	02-PLU-89-4.6	Test panel	7	626.4	lbf
7594	02-PLU-89-4.6	Test panel	7	633.6	lbf
8591	02-PLU-89-4.6	Test panel	8	699.9	lbf
8592	02-PLU-89-4.6	Test panel	8	650.5	lbf
8593	02-PLU-89-4.6	Test panel	8	561.7	lbf
8594	02-PLU-89-4.6	Test panel	8	681.3	lbf
38191	09-INYO-190-122.3	Mattress Channel Lining	11-g PVC	1045.1	lbf
38192	09-INYO-190-122.3	Mattress Channel Lining	11-g PVC	984.3	lbf
38193	09-INYO-190-122.3	Mattress Channel Lining	11-g PVC	989.3	lbf
38194	09-INYO-190-122.3	Mattress Channel Lining	11-g PVC	994.7	lbf
49191	09-INYO-190-99	Mattress Channel Lining	4	866.2	lbf
49192	09-INYO-190-99	Mattress Channel Lining	4	827.6	lbf
49193	09-INYO-190-99	Mattress Channel Lining	4	729.7	lbf
49194	09-INYO-190-99	Mattress Channel Lining	4	705.9	lbf
3191	01-HUM-101-70	Test Panel	3	989.8	lbf
3192	01-HUM-101-70	Test Panel	3	1037.7	lbf
3193	01-HUM-101-70	Test Panel	3	1158.3	lbf
3194	01-HUM-101-70	Test Panel	3	1284.9	lbf
5191	01-HUM-101-70	Test Panel	5	605.9	lbf
5192	01-HUM-101-70	Test Panel	5	641.8	lbf
5193	01-HUM-101-70	Test Panel	5	609.8	lbf
5194	01-HUM-101-70	Test Panel	5	632.2	lbf

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Ultimate Tensile Force Data   Individual Wires of Gabion Mesh
AFTER Various Exposures (see Table 3A)

Lot	Dist-Co-Rte-PM	Sub-location	Product No.	Force	Unit
7191	01-HUM-101-70	Test Panel	7	599.7	lbf
7192	01-HUM-101-70	Test Panel	7	596.5	lbf
7193	01-HUM-101-70	Test Panel	7	635.7	lbf
7194	01-HUM-101-70	Test Panel	7	595.0	lbf
5191	05-MON-1-7.5	As-Built Mattress N-RSP	5	731.4	lbf
5192	05-MON-1-7.5	As-Built Mattress N-RSP	5	632.9	lbf
5193	05-MON-1-7.5	As-Built Mattress N-RSP	5	730.6	lbf
5194	05-MON-1-7.5	As-Built Mattress N-RSP	5	724.3	lbf
4191	05-MON-1-8.1	Test Panel North Wall	4	650.6	lbf
4192	05-MON-1-8.1	Test Panel North Wall	4	656.6	lbf
4193	05-MON-1-8.1	Test Panel North Wall	4	741.7	lbf
4194	05-MON-1-8.1	Test Panel North Wall	4	784.8	lbf
5198	05-MON-1-8.1	Test Panel - Blazed	5	505.6	lbf
5198	05-MON-1-8.0	Test Panel - Blazed	5	308.8	lbf
5191	05-MON-1-7.7	Test Panel South Wall	5	622.6	lbf
5192	05-MON-1-7.7	Test Panel South Wall	5	689.0	lbf
5193	05-MON-1-7.7	Test Panel South Wall	5	646.6	lbf
5194	05-MON-1-7.7	Test Panel South Wall	5	727.2	lbf
4191	05-MON-1-7.7	Test Panel South Wall	4	667.5	lbf
4192	05-MON-1-7.7	Test Panel South Wall	4	650.7	lbf
4193	05-MON-1-7.7	Test Panel South Wall	4	754.9	lbf
4194	05-MON-1-7.7	Test Panel South Wall	4	784.1	lbf
4191	02-PLU-89-5.29	Invert near Culvert Inlet	4	466.2	lbf
4192	02-PLU-89-5.29	Invert near Culvert Inlet	4	463.4	lbf
4193	02-PLU-89-5.29	Invert near Culvert Inlet	4	282.6	lbf
4194	02-PLU-89-5.29	Invert near Culvert Inlet	4	496.6	lbf
1191	02-PLU-89-5.3	Overflow at Toe of Slope	1	912.8	lbf
1192	02-PLU-89-5.3	Overflow at Toe of Slope	1	831.9	lbf
1193	02-PLU-89-5.3	Overflow at Toe of Slope	1	919.3	lbf
1194	02-PLU-89-5.3	Overflow at Toe of Slope	1	826.7	lbf
2191	02-PLU-89-5.3	Overflow at Toe of Slope	2	1526.7	lbf
2192	02-PLU-89-5.3	Overflow at Toe of Slope	2	1505.9	lbf
2193	02-PLU-89-5.3	Overflow at Toe of Slope	2	1468.4	lbf
2194	02-PLU-89-5.3	Overflow at Toe of Slope	2	1505.9	lbf
3191	02-PLU-89-5.3	Overflow at Toe of Slope	3	1114.8	lbf
3192	02-PLU-89-5.3	Overflow at Toe of Slope	3	1226.8	lbf
3193	02-PLU-89-5.3	Overflow at Toe of Slope	3	1213.1	lbf
3194	02-PLU-89-5.3	Overflow at Toe of Slope	3	1201.3	lbf
4191	02-PLU-89-5.3	Overflow at Toe of Slope	4	770.5	lbf
4192	02-PLU-89-5.3	Overflow at Toe of Slope	4	836.6	lbf
4193	02-PLU-89-5.3	Overflow at Toe of Slope	4	751.9	lbf
4194	02-PLU-89-5.3	Overflow at Toe of Slope	4	842.5	lbf
5191	02-PLU-89-5.3	Overflow at Toe of Slope	5	603.0	lbf
5192	02-PLU-89-5.3	Overflow at Toe of Slope	5	607.2	lbf
5193	02-PLU-89-5.3	Overflow at Toe of Slope	5	627.6	lbf
5194	02-PLU-89-5.3	Overflow at Toe of Slope	5	613.2	lbf

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Ultimate Tensile Force Data Individual Wires of Gabion Mesh
AFTER Various Exposures (see Table 3A)

Lot	Dist-Co-Rte-PM	Sub-location	Product No.	Force	Unit
6191	02-PLU-89-5.3	Overflow at Toe of Slope	6	771.5	lbf
6192	02-PLU-89-5.3	Overflow at Toe of Slope	6	805.5	lbf
6193	02-PLU-89-5.3	Overflow at Toe of Slope	6	827.7	lbf
6194	02-PLU-89-5.3	Overflow at Toe of Slope	6	727.4	lbf
7191	02-PLU-89-5.3	Overflow at Toe of Slope	7	685.8	lbf
7192	02-PLU-89-5.3	Overflow at Toe of Slope	7	648.1	lbf
7193	02-PLU-89-5.3	Overflow at Toe of Slope	7	649.5	lbf
7194	02-PLU-89-5.3	Overflow at Toe of Slope	7	653.7	lbf
8191	02-PLU-89-5.3	Overflow at Toe of Slope	8	706.5	lbf
8192	02-PLU-89-5.3	Overflow at Toe of Slope	8	698.8	lbf
8193	02-PLU-89-5.3	Overflow at Toe of Slope	8	677.9	lbf
8194	02-PLU-89-5.3	Overflow at Toe of Slope	8	678.1	lbf
1195	01-HUM-101-125.9	Wall Back in Creek +2yrs	1	766.9	lbf
1196	01-HUM-101-125.9	Wall Back in Creek +2yrs	1	749.5	lbf
1197	01-HUM-101-125.9	Wall Back in Creek +2yrs	1	852.9	lbf
1198	01-HUM-101-125.9	Wall Back in Creek +2yrs	1	855.1	lbf
1191	01-HUM-101-125.9	Test Panel	1	848.2	lbf
1192	01-HUM-101-125.9	Test panel	1	844.4	lbf
1193	01-HUM-101-125.9	Test Panel	1	847.8	lbf
1194	01-HUM-101-125.9	Test Panel	1	862.2	lbf
2191	01-HUM-101-125.9	Test Panel	2	1471.4	lbf
2192	01-HUM-101-125.9	Test Panel	2	1459.5	lbf
2193	01-HUM-101-125.9	Test Panel	2	1427.3	lbf
2194	01-HUM-101-125.9	Test Panel	2	1442.7	lbf
3191	01-HUM-101-125.9	Test Panel	3	1059.2	lbf
3192	01-HUM-101-125.9	Test Panel	3	1108.4	lbf
3193	01-HUM-101-125.9	Test Panel	3	1066.2	lbf
3194	01-HUM-101-125.9	Test Panel	3	1203.7	lbf
4191	01-HUM-101-125.9	Test Panel	4	755.4	lbf
4192	01-HUM-101-125.9	Test Panel	4	902.6	lbf
4193	01-HUM-101-125.9	Test Panel	4	763.9	lbf
4194	01-HUM-101-125.9	Test Panel	4	866.7	lbf
5191	01-HUM-101-125.9	Test Panel	5	579.3	lbf
5192	01-HUM-101-125.9	Test Panel	5	586.7	lbf
5193	01-HUM-101-125.9	Test Panel	5	599.6	lbf
5194	01-HUM-101-125.9	Test Panel	5	637.8	lbf
6191	01-HUM-101-125.9	Test Panel	6	811.3	lbf
6192	01-HUM-101-125.9	Test Panel	6	766.6	lbf
6193	01-HUM-101-125.9	Test Panel	6	829.0	lbf
6194	01-HUM-101-125.9	Test Panel	6	736.7	lbf
7191	01-HUM-101-125.9	Test Panel	7	607.0	lbf
7192	01-HUM-101-125.9	Test Panel	7	592.6	lbf
7193	01-HUM-101-125.9	Test Panel	7	595.0	lbf
7194	01-HUM-101-125.9	Test Panel	7	608.7	lbf
8191	01-HUM-101-125.9	Test Panel	8	713.1	lbf
8192	01-HUM-101-125.9	Test Panel	8	698.6	lbf
8193	01-HUM-101-125.9	Test Panel	8	683.3	lbf
8194	01-HUM-101-125.9	Test Panel	8	727.5	lbf

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Ultimate Tensile Force Data   Individual Wires of Gabion Mesh
AFTER Various Exposures (see Table 3A)

Lot	Dist-Co-Rte-PM	Sub-location	Product No.	Force	Unit
1191	01-HUM-101-127	Test Panel	1	845.9	lbf
1192	01-HUM-101-127	Test Panel	1	837.0	lbf
1193	01-HUM-101-127	Test Panel	1	847.5	lbf
1194	01-HUM-101-127	Test Panel	1	837.8	lbf
2191	01-HUM-101-127	Test Panel	2	1508.0	lbf
2192	01-HUM-101-127	Test Panel	2	1458.5	lbf
2193	01-HUM-101-127	Test Panel	2	1486.9	lbf
2194	01-HUM-101-127	Test Panel	2	1518.1	lbf
3191	01-HUM-101-127	Test Panel	3	1156.7	lbf
3192	01-HUM-101-127	Test Panel	3	1100.6	lbf
3193	01-HUM-101-127	Test Panel	3	1138.8	lbf
3194	01-HUM-101-127	Test Panel	3	1239.1	lbf
4191	01-HUM-101-127	Test Panel	4	773.0	lbf
4192	01-HUM-101-127	Test Panel	4	863.6	lbf
4193	01-HUM-101-127	Test Panel	4	770.5	lbf
4194	01-HUM-101-127	Test Panel	4	849.1	lbf
5191	01-HUM-101-127	Test Panel	5	643.0	lbf
5192	01-HUM-101-127	Test Panel	5	628.0	lbf
5193	01-HUM-101-127	Test Panel	5	647.7	lbf
5194	01-HUM-101-127	Test Panel	5	624.6	lbf
6191	01-HUM-101-127	Test Panel	6	818.5	lbf
6192	01-HUM-101-127	Test Panel	6	831.5	lbf
6193	01-HUM-101-127	Test Panel	6	786.3	lbf
6194	01-HUM-101-127	Test Panel	6	776.5	lbf
7191	01-HUM-101-127	Test Panel	7	621.7	lbf
7192	01-HUM-101-127	Test Panel	7	625.0	lbf
7193	01-HUM-101-127	Test Panel	7	686.0	lbf
7194	01-HUM-101-127	Test Panel	7	643.2	lbf
8191	01-HUM-101-127	Test Panel	8	708.8	lbf
8192	01-HUM-101-127	Test Panel	8	712.7	lbf
8193	01-HUM-101-127	Test Panel	8	681.6	lbf
8194	01-HUM-101-127	Test Panel	8	679.2	lbf