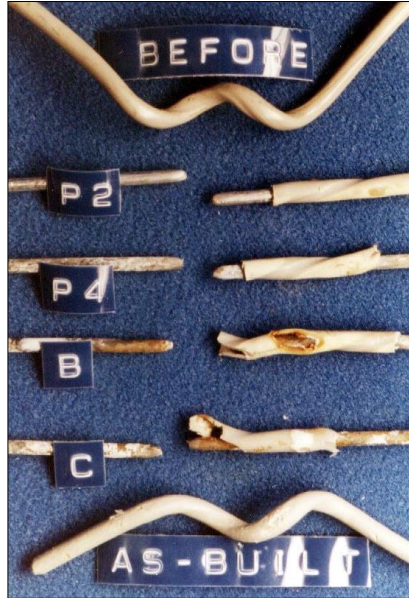
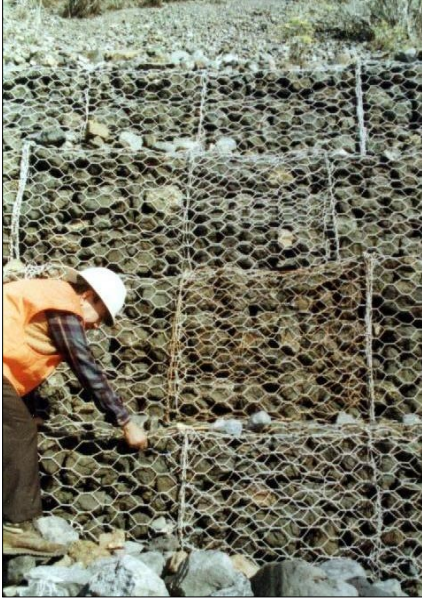




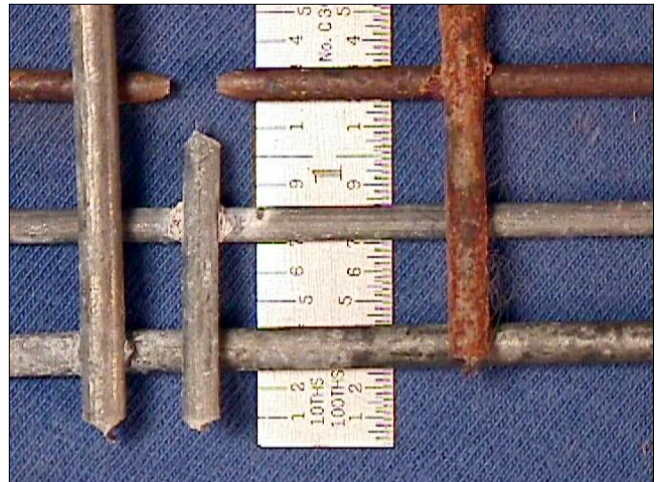
GABION MESH CORROSION

Field Study of Test Panels and Full-scale Facilities

by James A. Racine, 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)



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

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Final Report No. FHWA-CA-TL-99-23

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Performed by
Office of Structure Maintenance and Investigations
THOMAS M. RUT, P.E. Chief

Supervised by
Hydrology and Hydraulics Branch
PAUL ASKELSON, P.E. Chief
CATHERINE M. CROSSETT AVILA, P.E.
and
Office of State Highway Drainage Design
GLENN DeCOU, P.E. Chief

Co-Investigator, Co-Author
Office of Roadway Geotechnical Engineering North
THOMAS P. HOOVER, P.E. Acting Chief

Principal Investigator, Author
Office of State Highway Drainage Design
JAMES ANTHONY RACIN, P.E.



1. REPORT No. FHWA-CA-TL-99-23	2. GOVERNMENT ACCESSION No. PB2001-102895	3. RECIPIENT'S CATALOG No.	
4. TITLE AND SUBTITLE GABION MESH CORROSION Field Study of Test Panels and Full-scale Facilities		5. REPORT DATE 2nd edition NOV 2001 (1st ed. May 2001)	
		6. PERFORMING ORGANIZATION	
7. AUTHOR(S) JAMES A. RACIN and THOMAS P. HOOVER		8. PERFORMING ORGANIZATION REPORT No. 59312 637034	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Caltrans Engineering Service Center Structure Maintenance & Investigations - Hydrology & Hydraulics Branch 1891 Alhambra Blvd. Sacramento CA 95816		10. WORK UNIT No.	
		11. CONTRACT OR GRANT No. F93TL02 S	
		13. TYPE OF REPORT & PERIOD COVERED FINAL 1989 - 2000	
12. SPONSORING AGENCY NAME AND ADDRESS California Department of Transportation (Caltrans) Division of New Technology and Research 1101 R Street Sacramento CA 95814		14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This research was done in cooperation with the US Department of Transportation, Federal Highway Administration (FHWA), project title: Gabion Mesh Corrosion Comparisons: Continued Field Study			
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 1 st 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		18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public. National Technical Information Service (NTIS) 5285 Port Royal Road Springfield VA 22161 phone 1-800-553-6847	
19. SECURITY CLASSIF. (OF THIS REPORT) UNCLASSIFIED	20. SECURITY CLASSIF. (OF THIS PAGE) UNCLASSIFIED	21. No. OF PAGES 149 (includes cover)	22. PRICE

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.

ACKNOWLEDGMENTS

We thank the following Caltrans people for their quality input, critiques, and help in field and laboratory work during this lengthy field study:

Allen Berry Orick Maintenance, Howard Laws Fortuna Maintenance, District 1
Dennis McBride, Dan Wing, Charlie Fielder, John Bulinski, Anthony Martinelli,
Friday Ululani, Lucy Kostrzewa, Kemset Moore Hydraulics, District 1
Roy Harding Project Development, Jim Cox Quincy Maintenance, District 2
John Cottier, Bob Stapely, Wally Mason, Darrel Uppendahl, Bob Davis South Lake Tahoe
Maintenance, District 3
Joe Peterson, Dixon Lau Hydraulics, Brian Kearny Geotechnical,
David Yam Erosion Control, Larry Jones Design, District 4
Jim Krankel, Mike Eul Willow Springs Maintenance, District 5
Lance Gorman, Lyn Wickham Hydraulics, Ron Richman, John Duffy Geotechnical
and Materials Lab, Phillip “Buzz” Betts and Bridge Crew, District 5
Tom Dayak Environmental, Truman Denio Hydraulics,
Geale Fitzpatrick Project Development, District 9
Jeff Funk, Cid Tesoro, Karen Jewel Hydraulics, District 11
John Rizzardo Headquarters Maintenance
Joel Magana, Suong Vu, Brie Furnis-Lawrence, Leland Mason Structure Hydraulics
Roswitha Fox Soils Lab, Jody Bollinger Grade Bench, Walt Richards, Bob Cramer, Glen
Weldon Structural Materials Testing Lab, Frank Reed, Rosme Aguilar Metallurgy, Doug
Parks, Dean Coats, Dick Carello, Rob Reis, Ernest Shih, Ken Koebbe Corrosion Lab,
Lisa Dobek, Andy Rogerson Chemistry Lab, Paul Benson Environmental, Caltrans Translab
Harold Hunt Aquatic Ecology, Infrastructure Research
Jim Moese Retaining Walls, Structure Design
Glenn DeCou State Hydraulic Engineer, Headquarters Highway Drainage Design
Scott Meyer Hydrology, CA State University Sacramento, Caltrans Stormwater Program

We also thank the resident engineers and field inspectors on several Caltrans construction contracts, as well as contractors and engineers in the private sector, who helped us to refine the Caltrans gabion material specifications and standard plans. Finally, we thank the following manufacturers, who donated production samples of gabion materials for the study, and who also participated in developing the Caltrans gabion material specifications and standard plans :

Bill Sr., Harold, and Billy Hilfiker, Suzanne Blackburn
Hilfiker Retaining Walls, Eureka, CA
Maurizio Dodi, Masimo Ciarla, Peter Passarelli
Maccaferri Gabions, West Sacramento, CA
Andrew Knott, Zvi Dagan
Riverdale Mills, Massachusetts
Bill Glass, Gary Osendorf
Terra Aqua Gabions, Reno, NV

J.A.R. and T.P.H.

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

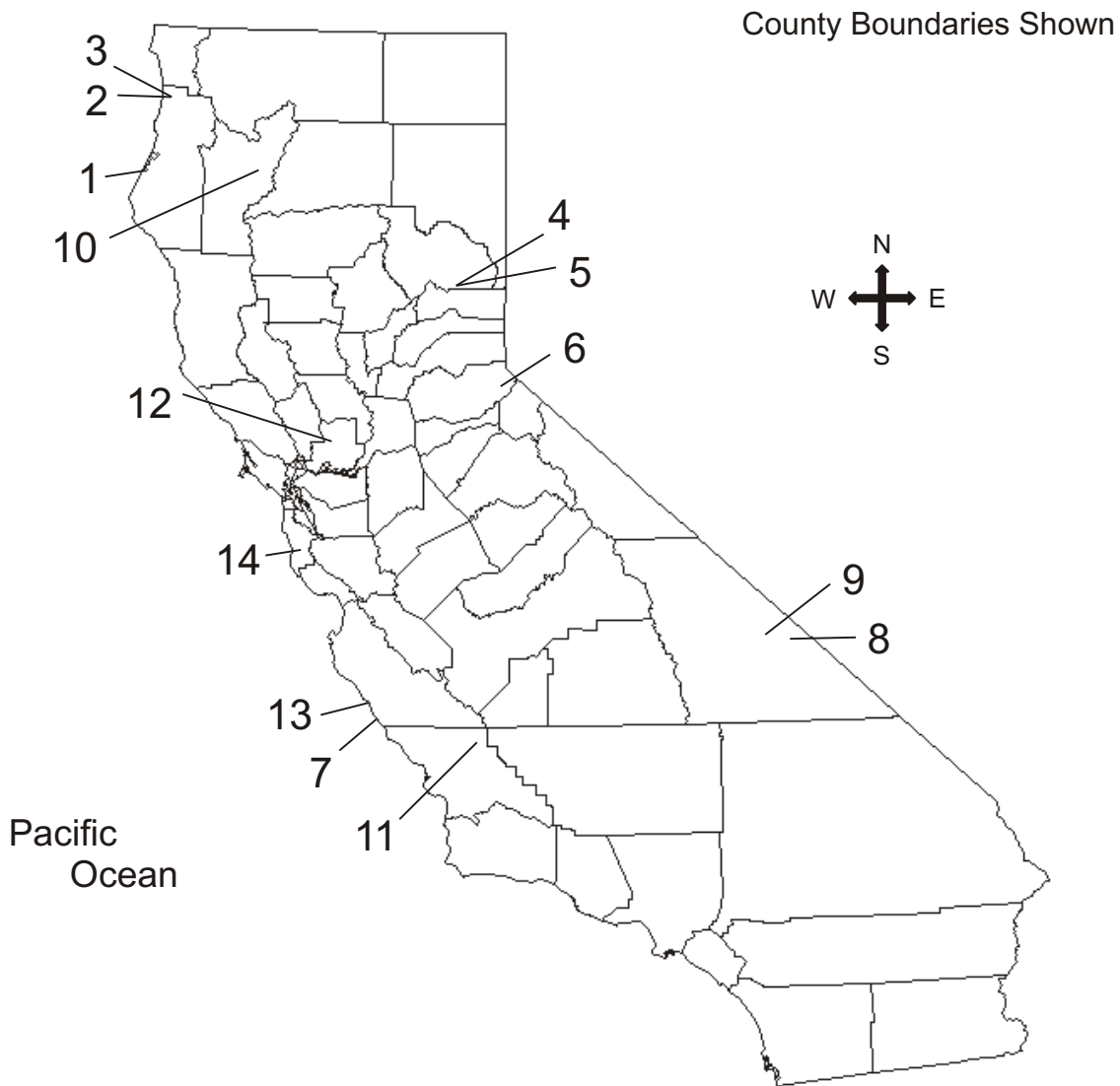


Table 1. Site Designations and Locations

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

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 corrosion occurred. Corrosion 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 galvanized 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 ordinary 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 corrosion, 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 corrosion. 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 fascia 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 corroded, 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, corrosion (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.

James A. Racin, P.E.

Caltrans Highway Drainage Design - Mail Station 28

PO Box 942874

Sacramento CA 94274-0001

voice 916-651-6550 fax 916-653-1446 e-mail jim.racin@dot.ca.gov