CORROSION OF GALVANIZED FASTENERS USED IN COLD-FORMED STEEL FRAMING

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Editors Note: This report, originally published in abbreviated form in May 2005 has been further substantially condensed to allow this very useful information to be published in Corrosion Management, the opportunity for which we are very grateful. The research, done in Hawaii, reflects a very similar marine environment to that experienced around the surf coasts of Australia, and provides a valuable insight into the durability issues associated with the use of fasteners in steel framed construction in coastal environments.

INTRODUCTION

This research program investigated the potential for corrosion of galvanized fasteners used in cold-formed steel framing by exposing test samples to a variety of environmental conditions frequently found in Hawaii and elsewhere. The results of this research will aid in the evaluation of galvanized fasteners in various exposure conditions.

Five field enclosures were constructed on the island of Oahu at coastal locations on both windward and leeward shores, and in the interior of the island. Each field enclosure represented various aspects of typical cold-formed steel construction and was equipped with a complete weather station. This report is an abbreviated version of the final report for this project. It outlines the design, construction and first two years of exposure of the field enclosures.

Standard cold-formed steel connections with galvanized screws have been placed in various locations within each of the field enclosures as a controlled study of the performance of galvanized fasteners in typical CFS framing construction. This report outlines the test results after 7 months exposure in the field enclosures. Identical screwed test connections have also been subjected to a cyclic salt spray routine in a corrosion chamber to induce accelerated corrosion. The effect of this cyclic routine on the strength and ductility of the connections is reported after 2700 cycles in the corrosion chamber.

Based on the results of this study, recommendations are made for the protection of cold-formed steel framing and fasteners in coastal environments.

ACKNOWLEDGEMENTS

This project was initiated by a joint effort of the Hawaii Pacific Steel Framing Alliance and the University of Hawaii Department of Civil and Environmental Engineering. Primary funding for this study was provided by the US Department of Housing and Urban Development (HUD).

Additional funding in the form of financial, material and labor donations were made by numerous individuals and corporations with an interest in cold-formed steel framing. The Steel Framing Alliance and a number of fastener manufacturers contributed financially towards the purchase of the cyclic corrosion chamber used in this study. These funds were augmented by a contribution from the College of Engineering at the University of Hawaii. In addition, the College of Engineering provided funds to purchase weather stations for each of the five field enclosures.

DETERMINATION OF TEST SITES

UH personnel identified five sites on military bases on Oahu as potential locations for the field enclosures. Permission was obtained from the appropriate authorities at each base to permit installation of the field enclosures and monitoring through September 2003. Extensions to these license agreements have made it possible to maintain the field enclosures for at least a further 2 years at all sites. The original intent was to utilize nearby airfield weather stations to determine meteorological data at the field sites. However, the microclimate at each site would not be identified by this means.

CORROSION TESTS

In order to accelerate the corrosion of connection specimens in the Structural Engineering Laboratory at UH, a cyclic corrosion chamber was purchased with funds from the UH College of Engineering and the Steel Framing Alliance. The chamber was installed and accelerated corrosion tests initiated once the field enclosures had been established.

During the initial literature review, and subsequent literature searches, a number of accelerated corrosion test procedures were evaluated. A cyclic wetting and drying salt spray test routine was selected for the initial corrosion chamber tests since it provided the best simulation of atmospheric conditions. A series of test connections have been subjected to this corrosion routine with selected specimens removed at weekly intervals for testing. The corrosion condition of the screws was calibrated to the reduction in shear strength of the screwed lap splice connections.

ENCLOSURE DESIGN

Five field enclosures were constructed, at various sites on Oahu, to imitate real-world conditions. Industry standard construction methods were used to construct enclosures that incorporate a wide range of commonly used construction techniques and materials. The FEMA Technical Bulletin 8-96 on Corrosion Protection for Metal Connectors in Coastal Areas (FEMA 1996) was used to guide the development of the field enclosures. This FEMA funded study investigated the performance of galvanized sheet metal connector plates used in timber construction when subjected to different field exposure conditions.

Five exposure conditions were identified:

- Partially sheltered exterior exposures (e.g. crawl space and eaves)
- Boldly exposed exterior exposures (e.g. exterior walls and roof)
- Vented enclosed exposures (e.g. attic space)
- Unvented enclosed exposures (e.g. sealed wall and floor cavities)
- Interior living space exposures (e.g. inside air-conditioned occupied space)

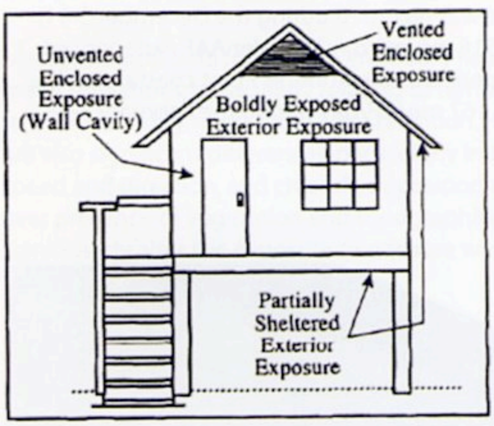
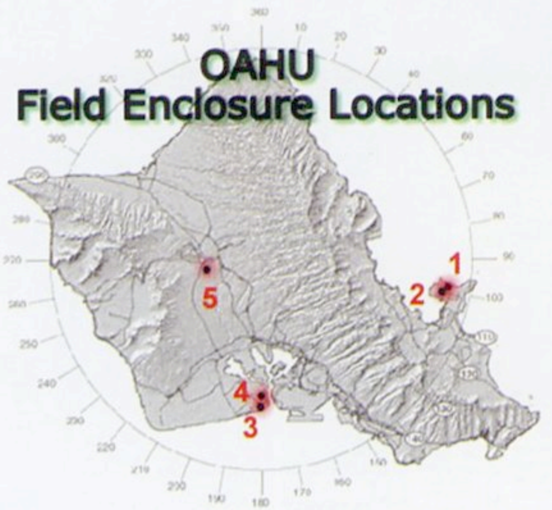


Figure 1: Exposure Conditions (FEMA)

Station Location Environmental Exposure Condition

1. Kaneohe Marine Corps Base Hawaii, Coastal (230 meters from coastline)
2. Kaneohe Marine Corps Base Hawaii, Inland Intermediate (535 meters from coastline)
3. Iroquois Point Naval Housing, Coastal (55 meters from coastline)
4. Iroquois Point Naval Housing, Inland Intermediate (550 meters from coastline)
5. Wheeler Army Airfield, Interior Inland (beyond 1000 meters from coastline)



Field Enclosure – Construction stages

Iroqois Point Site – Inland looking East

MCBH coastal site looking NE

METEOROLOGICAL INSTRUMENTATION

In order to correlate corrosion rate to in-service conditions, the field enclosure environment must be monitored. The following is a list of monitored parameters at each field enclosure site:

- External Temperature
- External Relative Humidity
- Internal Temperature (4 locations housing test connection samples)
- Internal Relative Humidity (4 locations housing test connection samples)
- Wind Speed
- Wind Direction
- Rainfall
- Solar radiation levels
- Atmospheric chloride levels

CHLORIDE DEPOSITION RATE

Chloride candles have been used at each of the field enclosures to determine chloride deposition rates over a 6 month period. Each candle was exposed for an average duration of two weeks. When a sample was recovered from the field, purified water was added to the field sample to produce 400mL of solution. A 100mL sample of the diluted solution was then analyzed for its molar chloride concentration based on the known level of purified water in the flask. These tests were performed using an ion-selective electrode in the Corrosion Laboratory of the Mechanical Engineering Department at the University of Hawaii. Based on the exposed area of the candle wick, the measured chloride concentration is converted to a chloride deposition rate in mg/m²/day. This represents the average deposition rate during the candle exposure period.

Wheeler AAF Site

Chloride deposition rates vary from 80-580 mg/m²/day range. The highest rate was recorded during the December 5-11, 2003 period at 581 mg/m²/day. The lowest rate was 80mg/m²/day, during the January 5 to February 3, 2004 period.

Iroquois Point Coastal Site

The highest rate was recorded during the December 5-11, 2003 period at 516 mg/m²/day. Wheeler AAF experienced the same peak period as the Iroquois Point coastal site. The lowest rate was 167 mg/m²/day during the February 3-28, 2004 period.

Crawl space exposed floor joists - MCBH Coastal site after 16 months.

Iroquois Point Inland Site

The highest rate was recorded during the December 5-11 period at 669 mg/m²/day. Iroquois Point inland experienced the same peak period as the Iroquois Point coastal and the Wheeler AAF site. The lowest rate was 105 mg/m²/day, during the November 14 to December 5, 2004 period.

Marine Corps Base Coastal Site

Chloride deposition rates for Marine Corps Base coastal fall within the 216-2883 mg/m²/day range, a significant increase over deposition rates for Wheeler AAF and Iroquois Point sites. The highest rate was seen during the November 26 to December 18 period at 2883 mg/m²/day. The lowest rate was 216 mg/m²/day, during the December 18, 2003 to January 13, 2004 period.

Marine Corps Base Inland Site

Chloride deposition rates for Marine Corps Base Inland fall within the 165-768 mg/m²/day range, a significant decrease from deposition rates for the coastal site. The highest rate was seen during the November 26 to December 18 period at 768 mg/m²/day, less than one third the rate seen at the coastal site for the same period.

CONCLUDING OBSERVATIONS

Meteorological data for the five enclosure field sites show many similarities, particularly relating to temperature and relative humidity, rainfall and solar radiation. However, there are also significant differences, particularly in terms of wind speed and direction, and chloride deposition rates, even over presence of vegetation and topographical features can significantly alter the exposure to onshore winds carrying salt spray.

Crawl space cripple wall and post, MCBH Coastal after 28 months.

Crawl space exposed floor joists, MCBH Coastal after 21 months.

The significant difference between the chloride deposition rates at the Iroquois Point coastal site compared with the Marine Corps Base coastal site is attributed to the following influencing factors:

- Prevailing winds on the Island of Oahu are from the N and NE, with less frequent winds from the S.
- Onshore wind speeds are generally much lower on southern shorelines than at the MCBH coastal site.
- Because of offshore reefs on the south shore, there is only small shoreline wave action at the Iroquois Point coastline, compared with significant open ocean swells breaking on the MCBH coastline. In addition, the Iroquois shoreline is a relatively flat sandy beach while the shoreline at the MCBH coastal site is a combination of steep beach and rocky outcrops.
- There is vegetation between the shoreline and the Iroquois Point sites, while the coastal site at MCBH is fully exposed to the onshore winds. More conclusive results could be made if the chloride deposition rates were monitored more frequently, over periods with predominantly the same wind speed and direction. In addition, information on surf heights would confirm the relation of higher chloride deposition rates to breaking wave size.

SUMMARY OF FIELD ENCLOSURE OBSERVATIONS

After 20 months field exposure, the enclosure at Wheeler Army Airfield and the inland enclosure at Iroquois Point showed only minor signs of corrosion of framing fasteners in the fully exposed crawl space posts. No corrosion was noted in the exposed floor joists, vented attic or enclosed wall framing. After the same exposure, the coastal enclosure at Iroquois Point exhibited similar behavior, with the addition of the initiation of corrosion of fasteners and cut ends of CFS framing in the vented attic.

In contrast, fully exposed CFS members and fasteners in the crawl space of the coastal enclosure at MCBH showed initiation of corrosion after as little as 5 months exposure. This corrosion proceeded rapidly so that by 28 months, the exposed floor joists and supporting posts and cripple wall have experienced severe corrosion. Areas of the floor joists that were enclosed by plywood sheathing show very little signs of corrosion except where exterior air has leaked into the enclosed space through unsealed edge joints.

After 28 months, fasteners in the vented attic at the MCBH coastal enclosure experienced significant corrosion. The CFS roof framing members were tarnished with some cut end corrosion. Similar corrosion was noted in the wall with lap siding and no vapor barrier, while the walls with lap siding and vapor barrier, or plywood sheathing, only showed signs of corrosion at the top plate that was exposed to air in the vented attic.

It was noted that the ETF pins used to secure the Hardie Board and plywood sheathing had less ferrous oxide corrosion than the framing screws for the same exposure conditions.

The MCBH inland enclosure exhibited corrosion levels significantly less than the coastal site, but more severe than any of the Iroquois or Wheeler sites. The additional distance from the coastline, and the intervening vegetation appear to have provided significant protection for this enclosure

SUMMARY

This report details the design, construction and first two years of exposure of five field enclosures constructed on the island of Oahu. The enclosures each represent typical residential cold-formed steel construction and are equipped with weather stations. The field sites selected for this study represent coastal and near-coastal conditions on windward and leeward shores of Oahu, and one interior site remote from the coast.

The cold-formed steel framing and fasteners in each enclosure were inspected visually at regular intervals for a two-year period after construction.

Standard cold-formed steel connections with galvanized screws were placed in various locations within each of the field enclosures as a controlled study of the performance of galvanized fasteners in typical CFS framing construction. Connection test results are provided after 7 months exposure in the field enclosures.

Standard screwed test connections were also subjected to a cyclic salt spray routine in a corrosion chamber to induce accelerated corrosion. The effect of this cyclic routine on the strength and ductility of the connections are reported after 2700 cycles in the chamber.

CONCLUSIONS

The following conclusions are based on 28 months of visual inspection of the cold-formed steel framing and fasteners at five field enclosure sites on the island of Oahu.

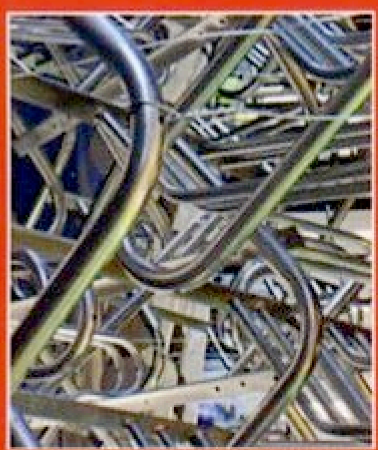
- The predominant factors affecting the rate of corrosion are the level of chlorides in the atmosphere, the wind speed and direction, and the degree of exposure for the cold-formed steel framing and galvanized fasteners.
- Framing and fasteners within enclosed wall and floor sections are protected from corrosive environments. Precautions must however be taken to prevent ingress of air-borne salts into these sections.
- In coastal environments with on-shore winds carrying significant salt spray, exposed cold-formed steel framing and fasteners in crawl spaces, vented attics or exterior exposure may corrode very rapidly.
- Vegetation or other obstructions between the coastline and the enclosure site can significantly reduce the salt content of the air, leading to less corrosion.
- Coastal environments with predominantly offshore winds experience significantly lower levels of corrosion on framing and fasteners in crawl spaces, vented attics or exterior exposure.

The following conclusions are based on tests of screwed lap splice connections exposed to 45 minute cycles of 0.1M NaCl salt spray (0.08% salt solution) and heated drying in an accelerated corrosion chamber.

- After 2772 cycles, the average failure strength of the screwed connections was the same as the original control specimens.
- After 2772 cycles, the average elongation at peak load had reduced to 80% of that experience in the control specimens.

NOVEMBER 2008
Vol. 15 No 2

CORROSION MANAGEMENT



COVER

This abstract image is a load of hot-dip galvanized hand rails and ladders just out of the galvanizing bath and waiting to be unloaded and inspected.

PUBLISHER

Industrial Galvanizers Corporation Pty Ltd.

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This cable tray column is badly stained by 'white rust' caused by prolonged storage on site in packs during a period of wet weather. Where does the responsibility lie? - Page 24

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NOVEMBER 2008
Vol. 15 No 2
Registered by Australia Post
PP No. 229640/00002

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