Corrosion of Galvanized Fasteners used in Cold-Formed Steel Framing

by
Ian N. Robertson Ph.D., P.E.

Steel Framing Alliance
and
University of Hawaii

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& Steel Framing Alliance
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Outline

- HUD project overview
- Field study
- Laboratory study
- Field observations
- Recommendations

HUD Project Overview

- Concern over corrosion of CFS connection fasteners
- Initiated by HPSFA and UH in 2001
- Includes field and accelerated laboratory tests
  - Field tests - Evaluate rate of corrosion at various locations and climatic exposures on Oahu
  - Lab tests - Evaluate effect of various degrees of corrosion on connection strength
- Report results and prepare industry guideline

Field Enclosures

- Intended to represent typical housing construction
- Observe extent of corrosion on members and connections
- House test connection samples for future strength testing in laboratory
- Standard Steel and Zinc samples monitored for base corrosion rate
- Climatic conditions monitored

Typical field enclosure

Panel Pre-fabrication

MCBH – Construction

MCBH – Coastal Site

MCBH – Inland Site

Pre-Fabricated and stored at Hunt Building in Pearl City

Iroquois - Inland

Iroquois - Coastal

Wheeler AAF

Field enclosure locations

Windward Coastal:

1 - Kaneohe MCBH – 230 m

Windward near coast:

2 - Kaneohe MCBH – 535 m

Leeward Coastal:

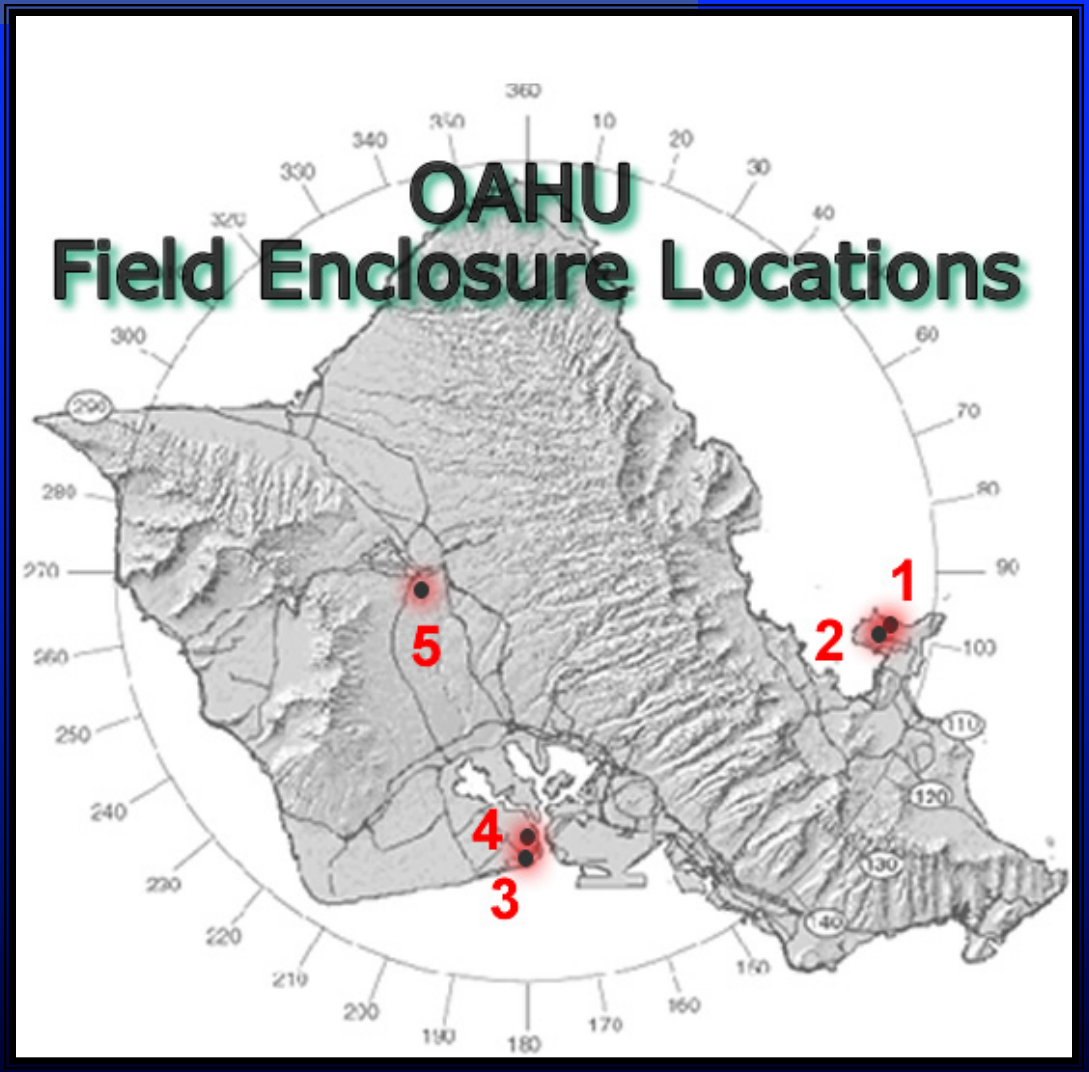
3 - Iroquois Point – 55 m

Leeward near coast:

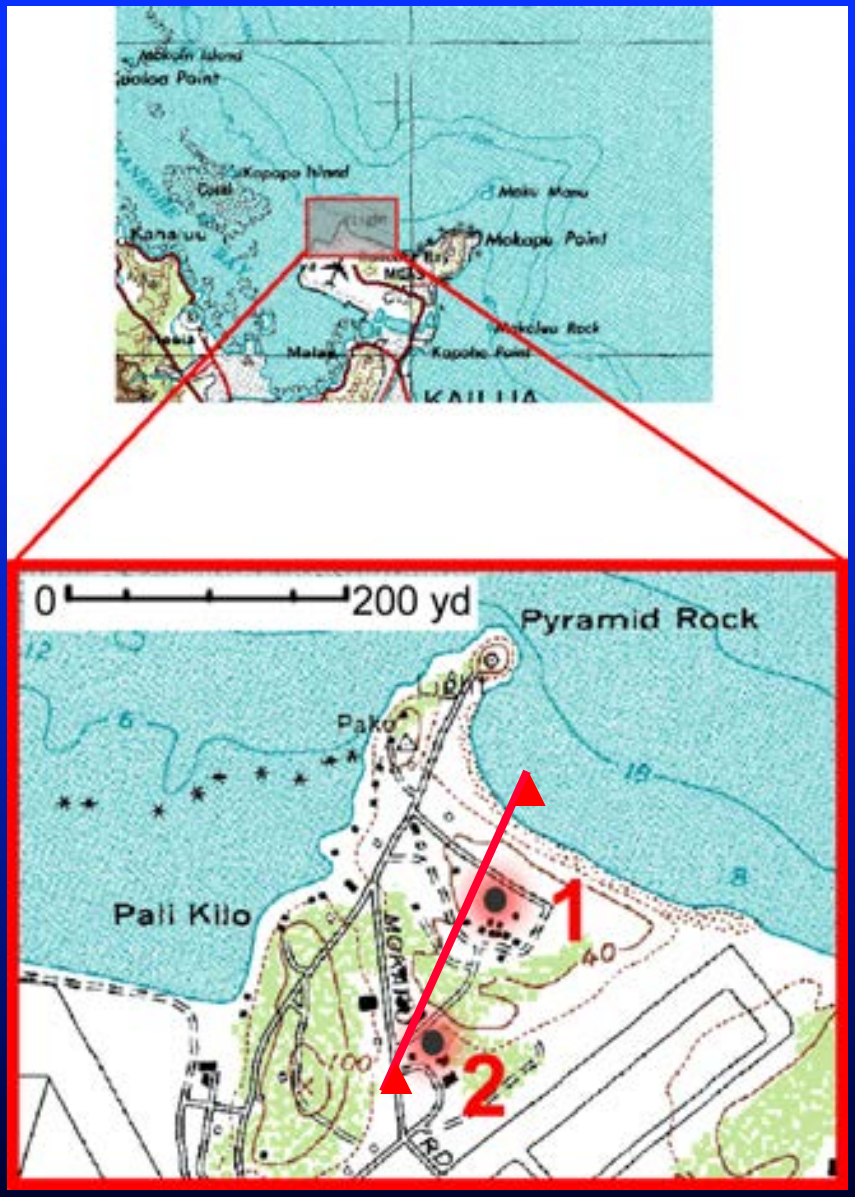
4 - Iroquois Point – 550 m

Inland:

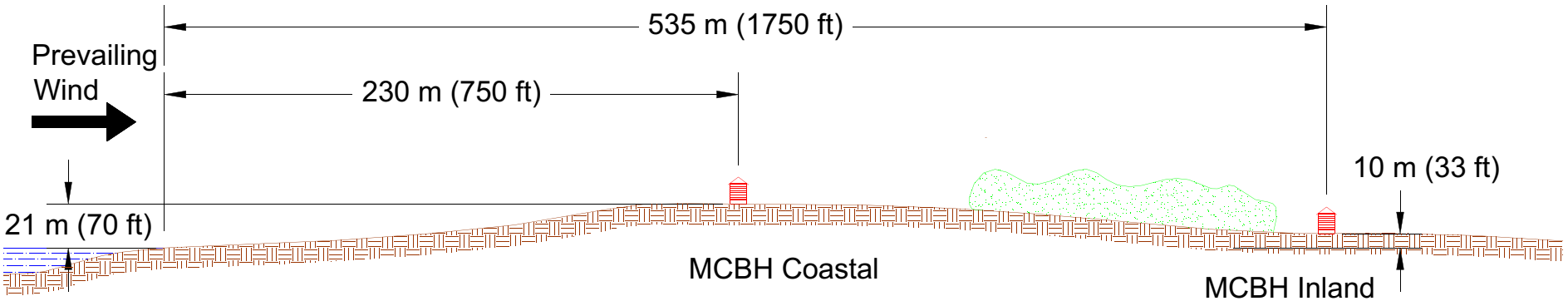
5 – Wheeler AAF - > 1000 m



Kaneohe MCBH

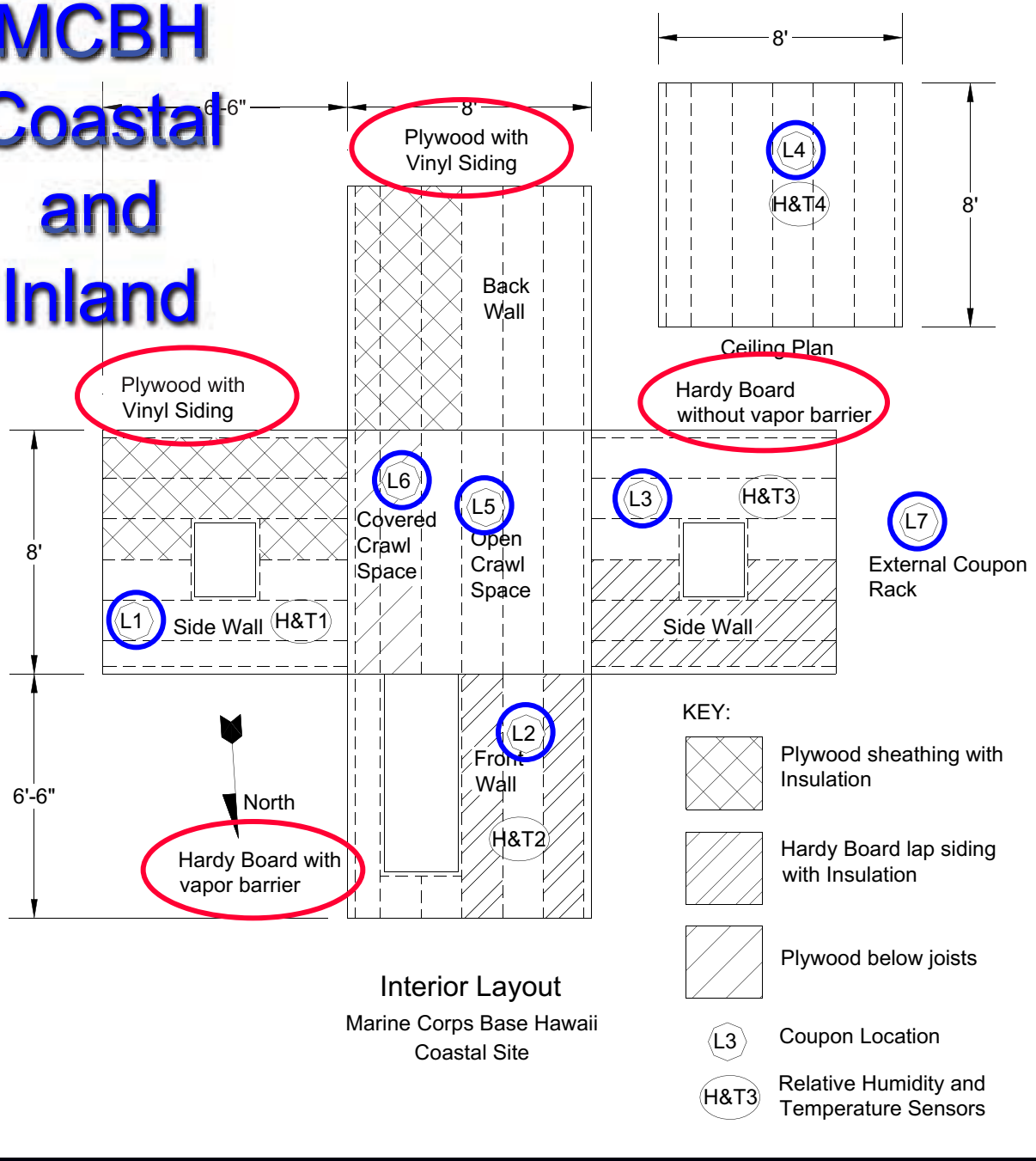


MCBH Profile

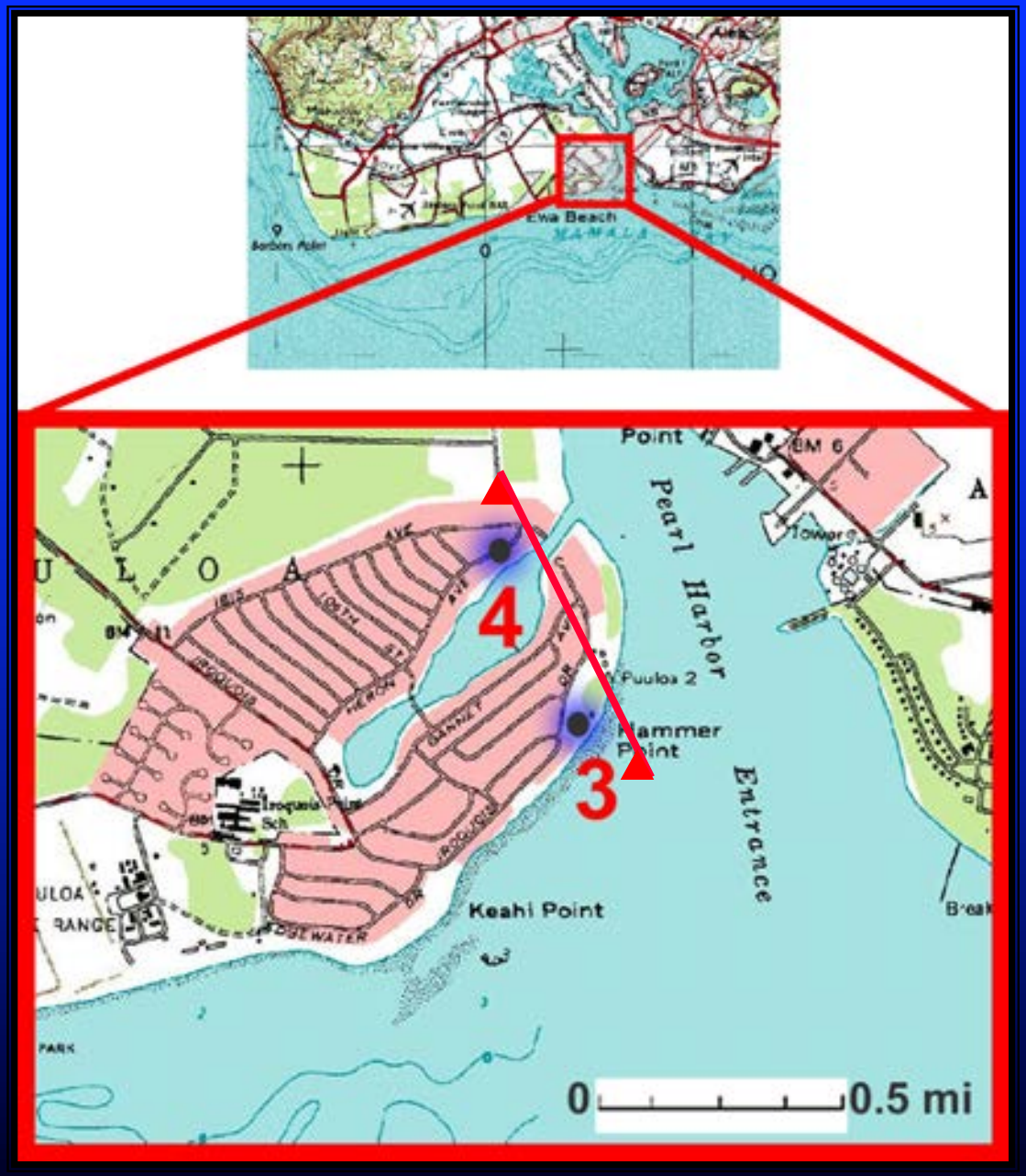


Kaneohe MCBH - Coastal

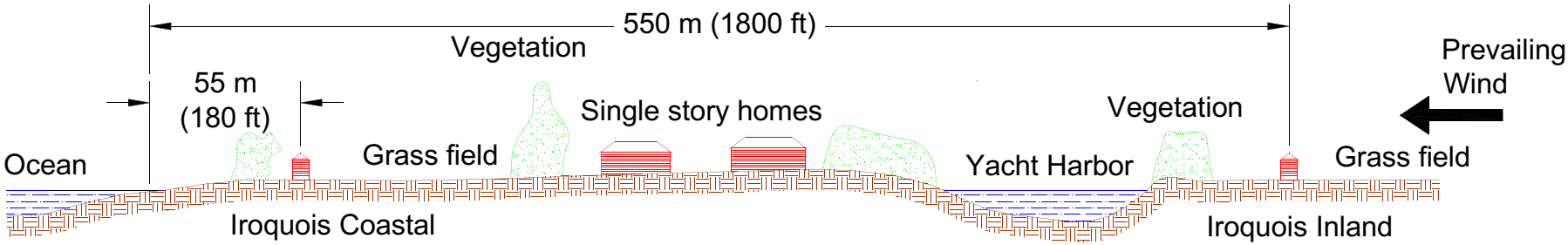
MCBH Coastal and Inland



Iroquois Point



Iroquois Profile

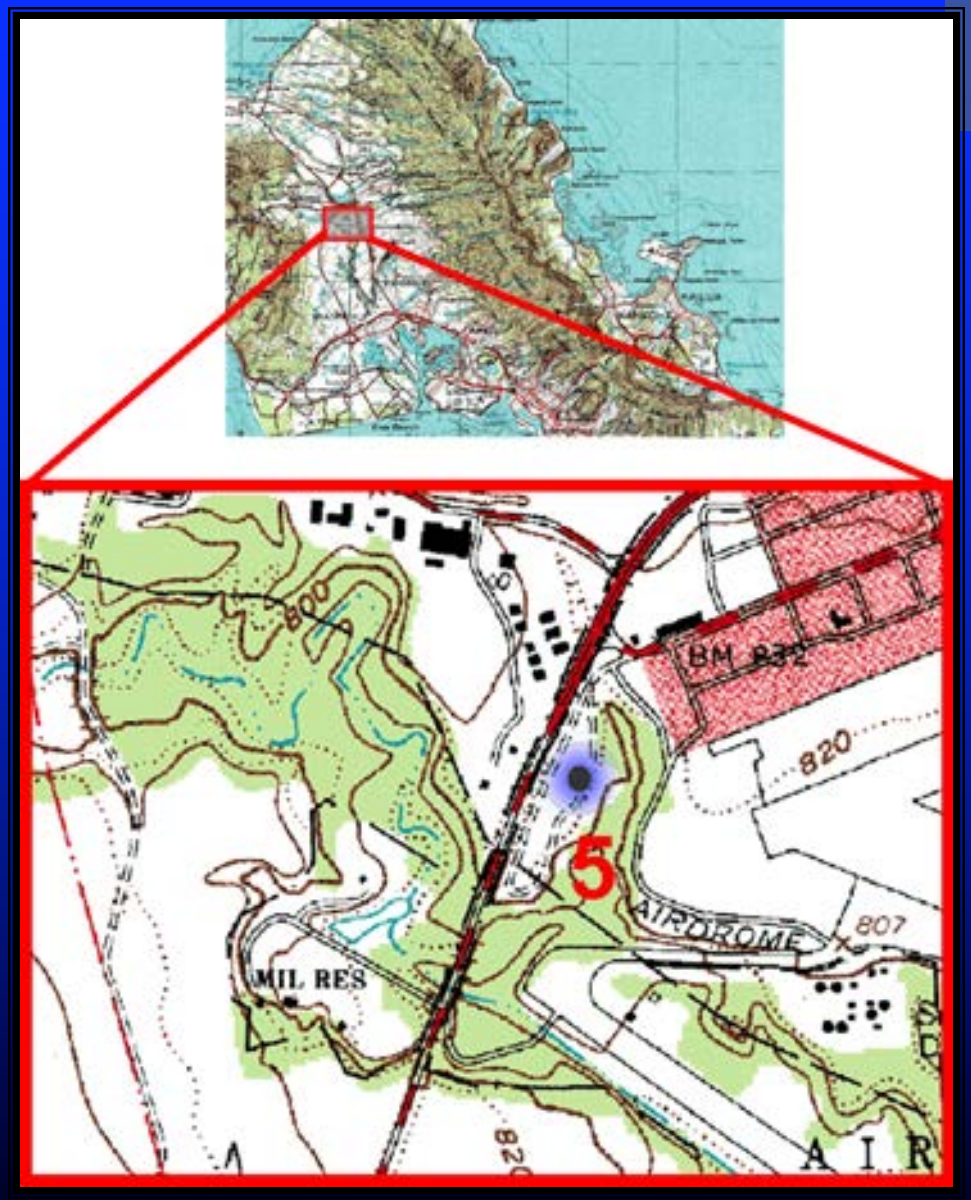


Iroquois Enclosures

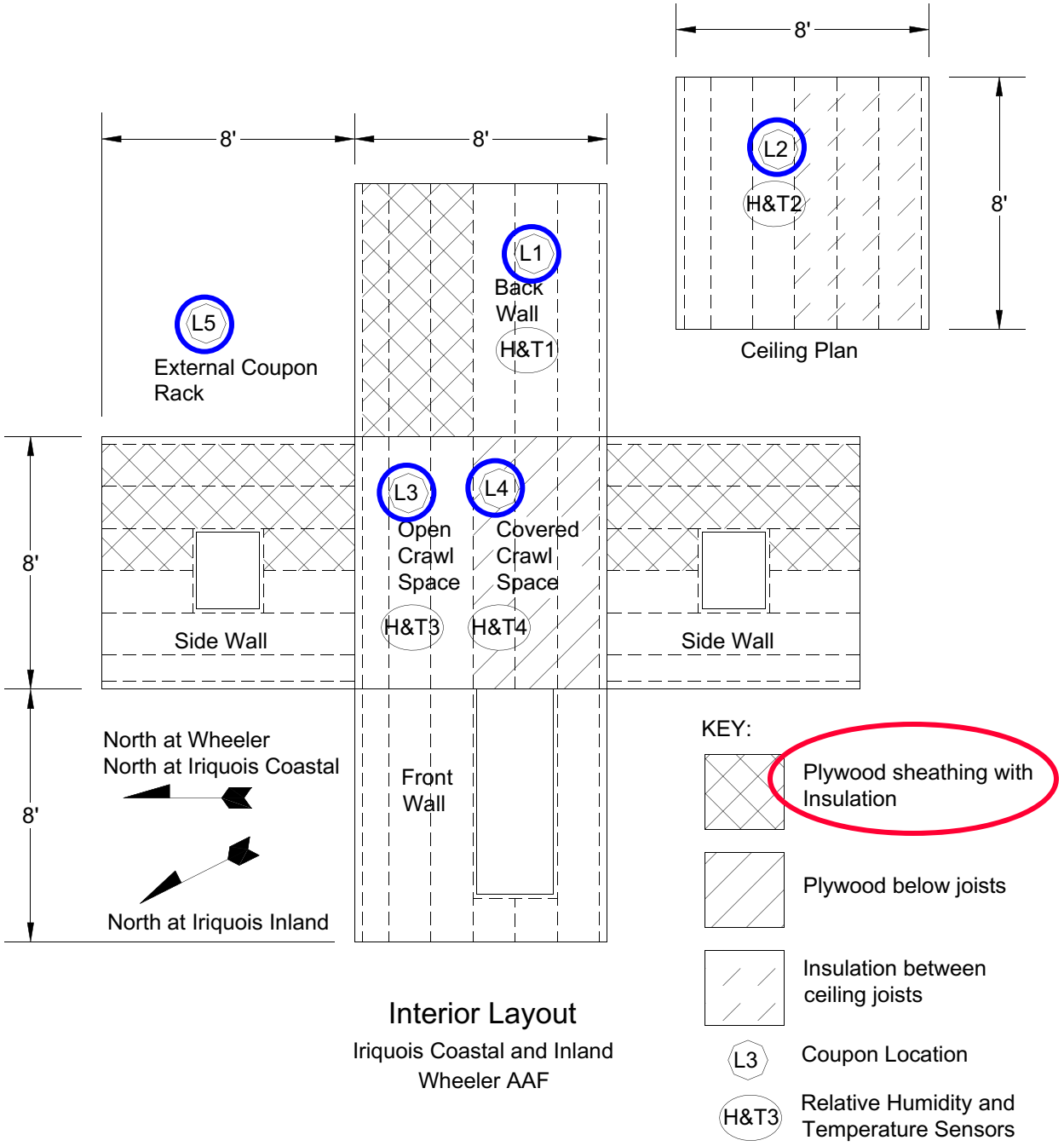
Iroquois Coastal

Iroquois Inland

Wheeler Army Airfield



Iroquois Coastal, Iroquois Inland and Wheeler AAF

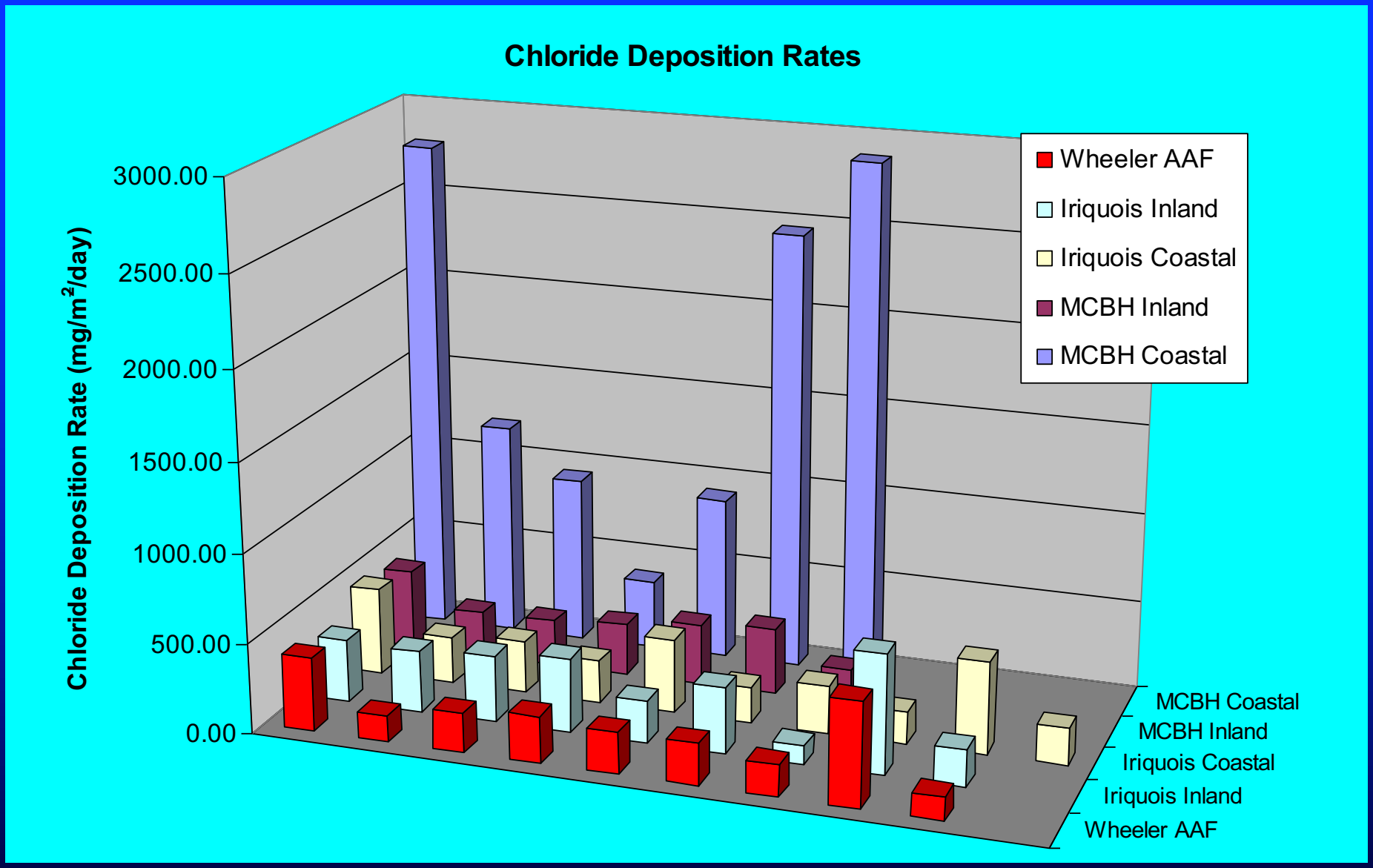


Atmospheric Instrumentation

- UH College of Eng. - $25,000 funding
- Five identical weather stations
- One located at each site
- Campbell Scientific instruments and datalogger
  - Wind speed and direction
  - Rainfall
  - Solar radiation
  - Exterior RH and temperature
  - Interior RH and temperature

Atmospheric Chloride Candle

- Atmospheric chloride deposition rate
- Covered for rain protection
- Reported as $mgCl/m^2/day$

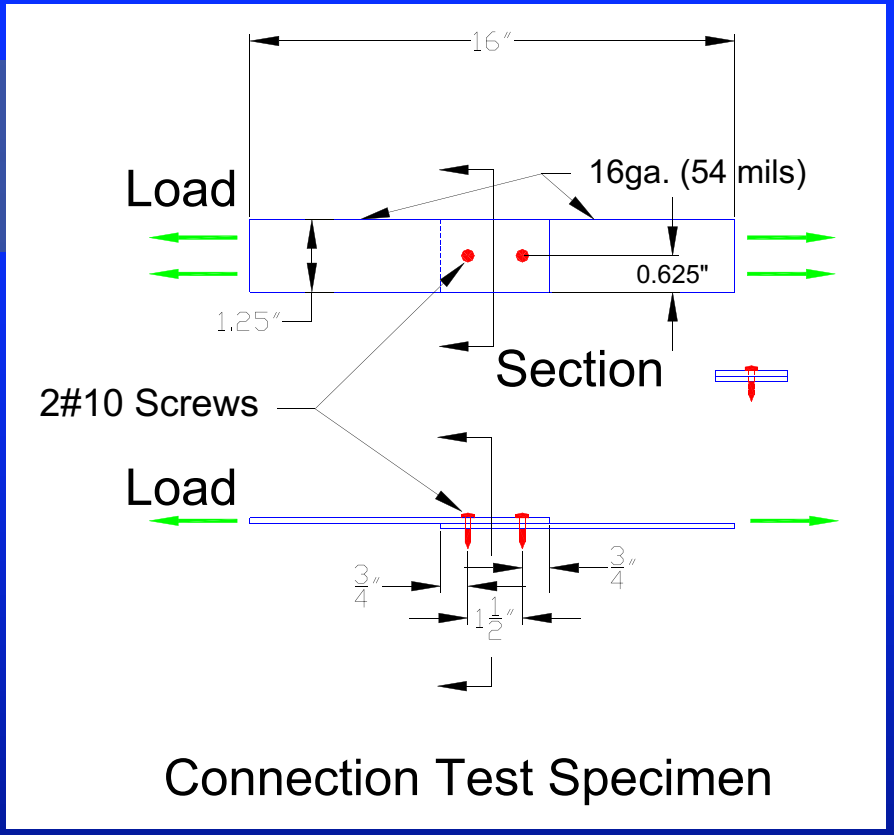

Chloride Deposition Rates
Chloride Deposition Rate (mg/m²/day)
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Wheeler AAF
Iriquois Inland
Iriquois Coastal
MCBH Inland
MCBH Coastal
MCBH Coastal
MCBH Inland
Iriquois Coastal
Iriquois Inland
Wheeler AAF

Field Test Connections

- Connection Selection:
  - (2) #10 screws
  - In lap splice of 1.25” wide 16 ga (54 mil) G60 galvanized plates (Zinc coating approx. 12.5 μm)

Lox-head

Hex-head



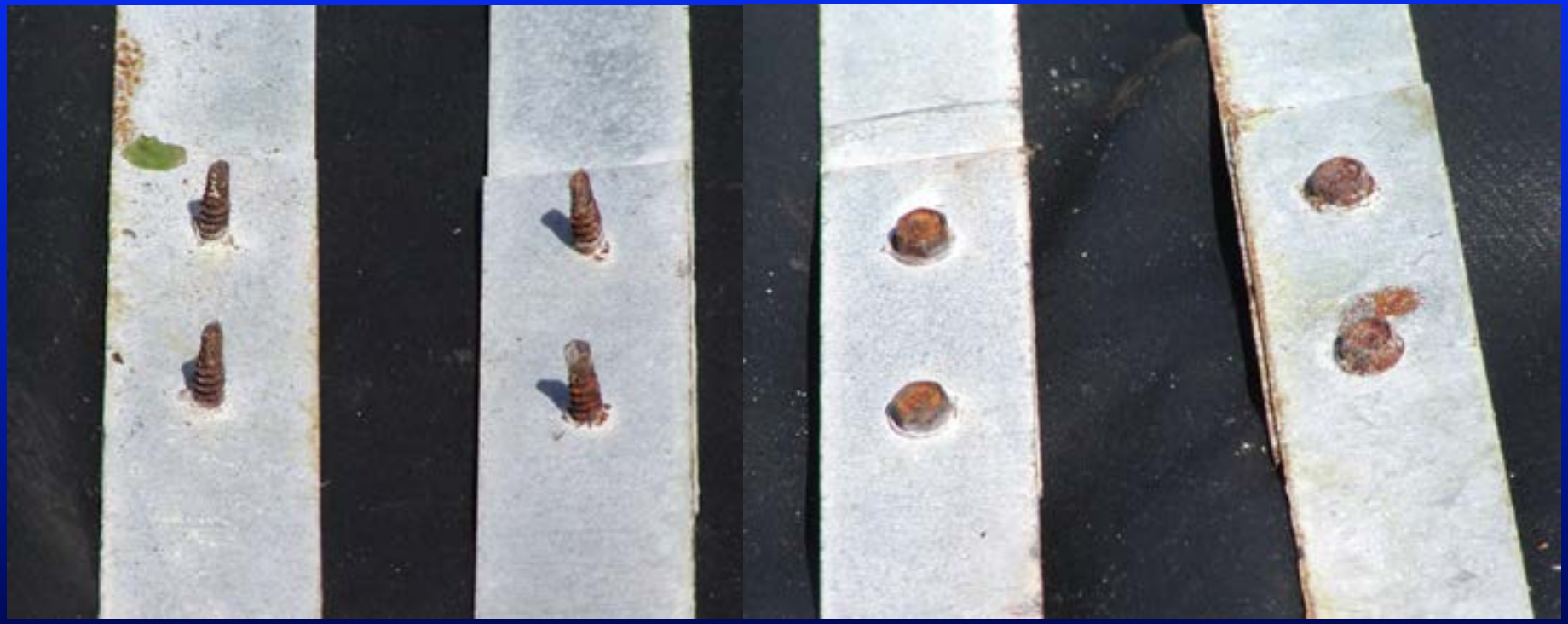
Connection Test Specimen

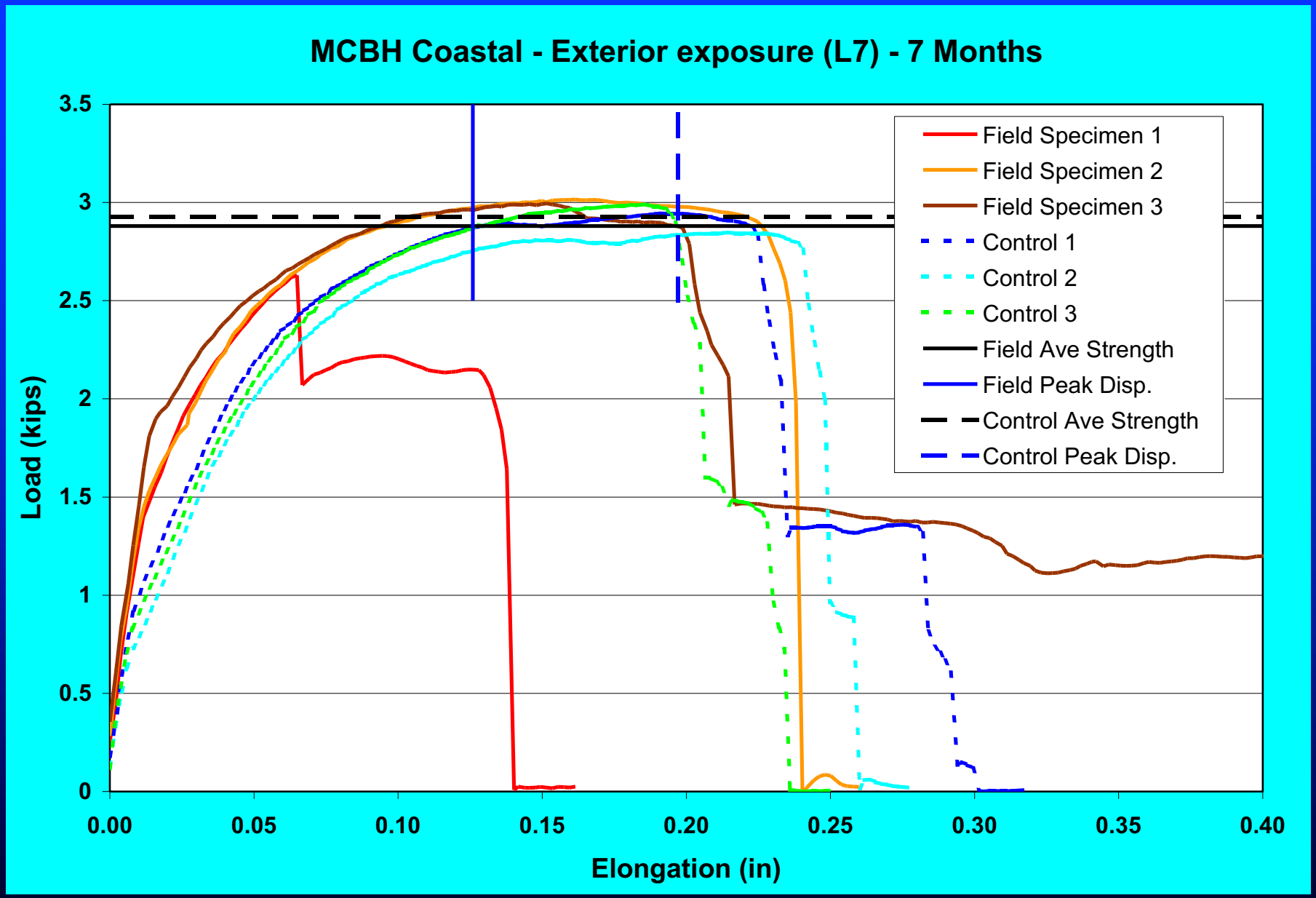
- Screw Selection:
  - #10 Hex head galvanized screws
  - Self-drilling, self-tapping
  - Zinc coating approx. 3 - 4 μm

Observations at MCBH Coastal

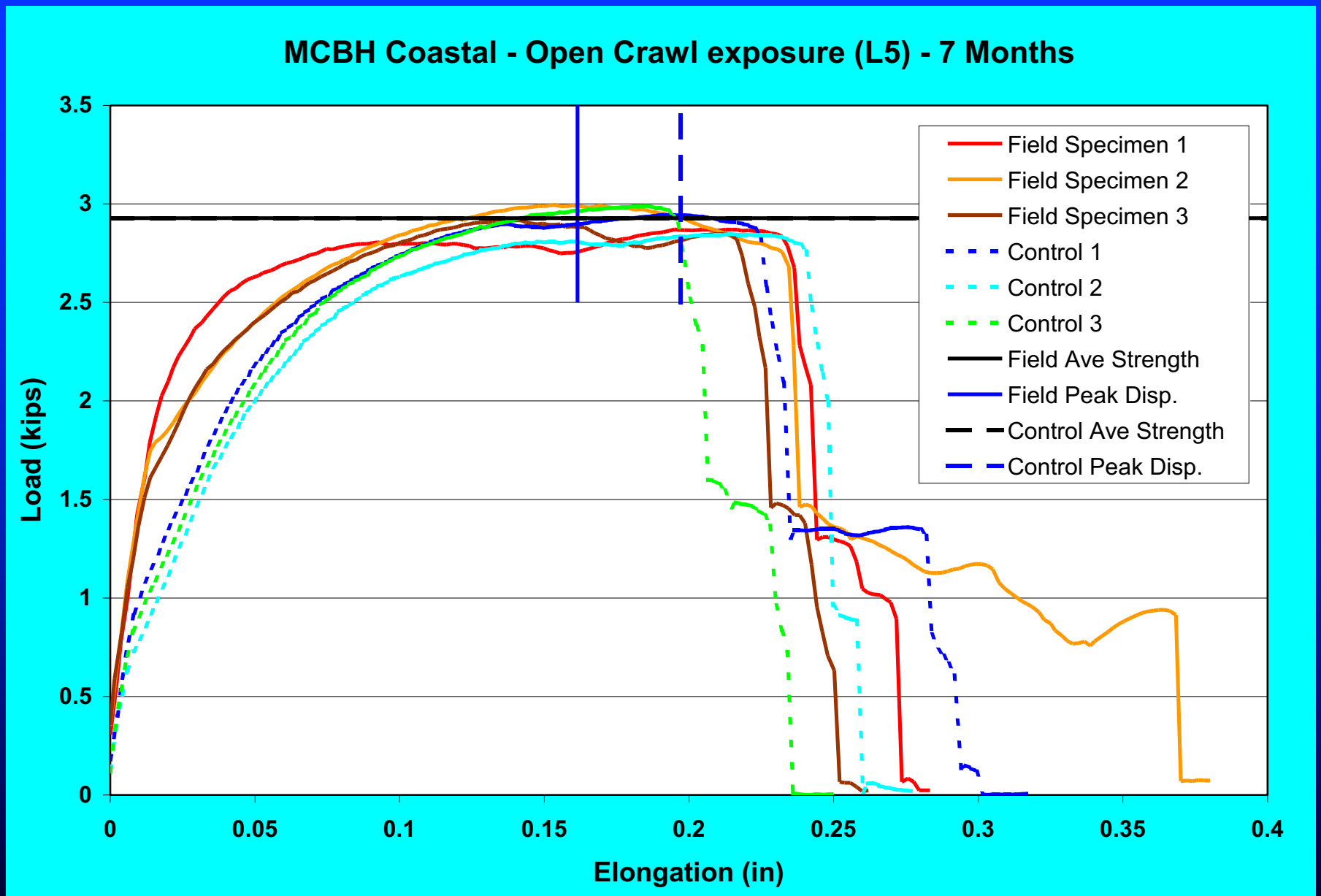
Exterior Connections

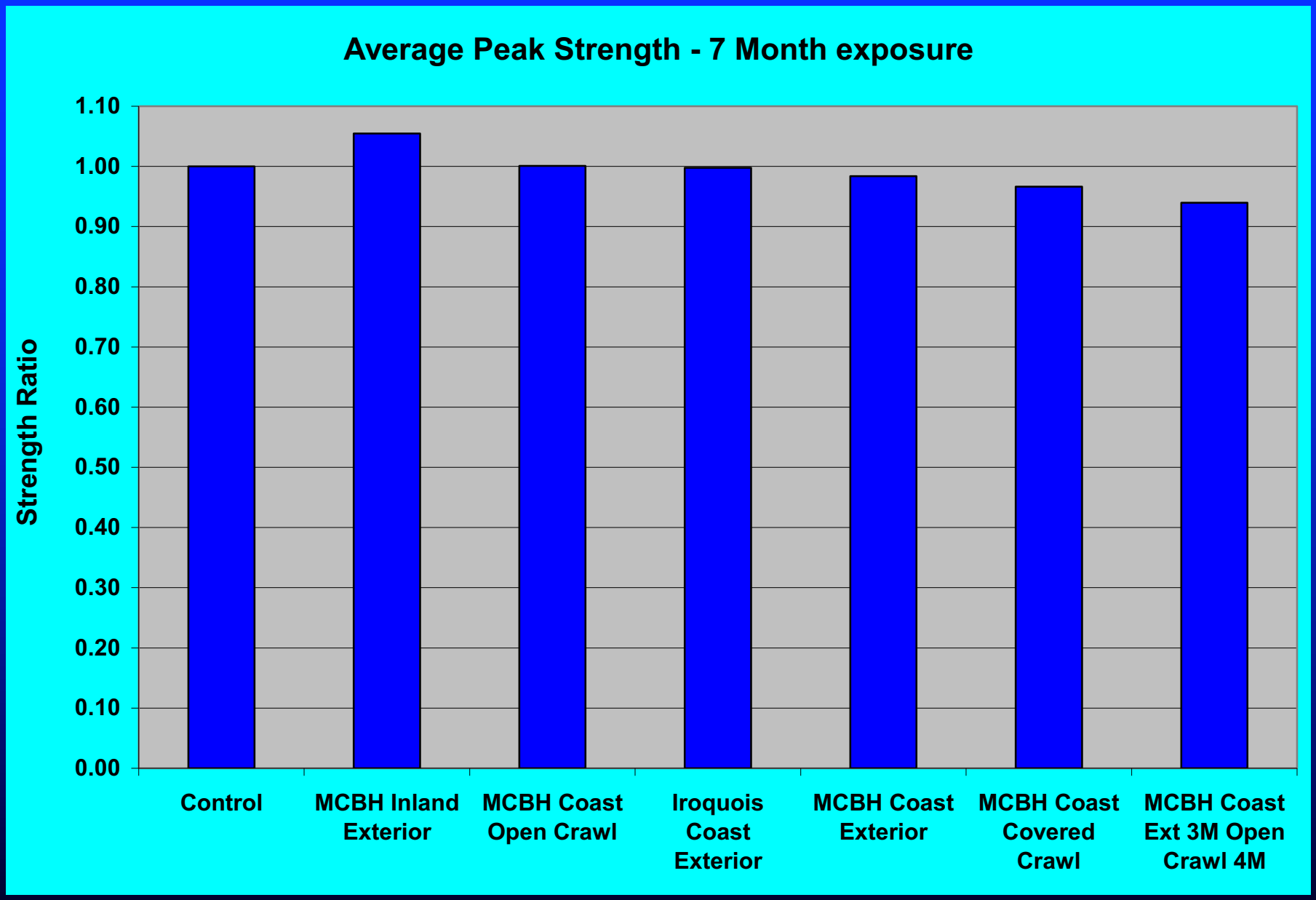
MCBH Coastal – Exterior Connections
7 Months Exposure

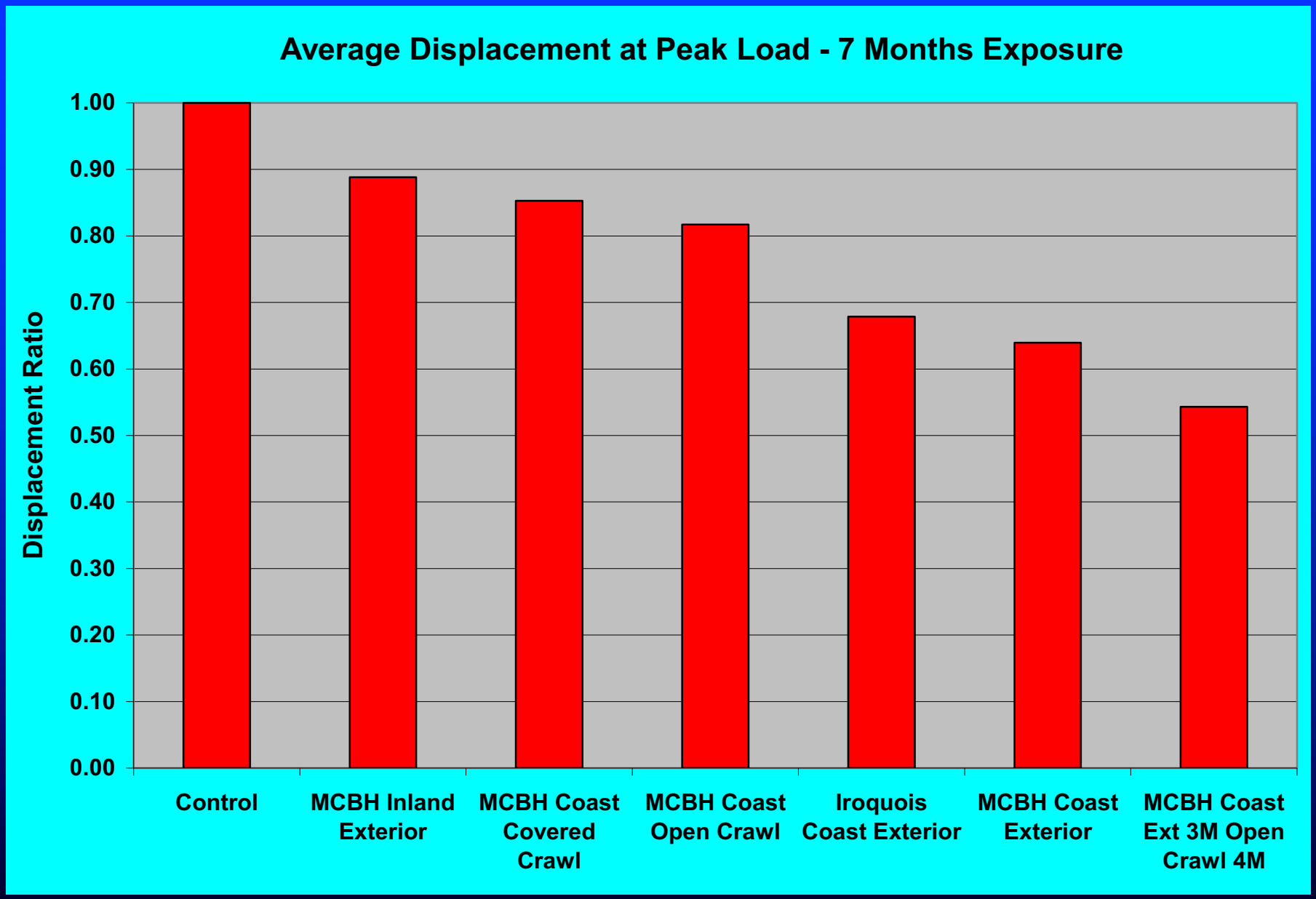



MCBH Coastal - Exterior exposure (L7) - 7 Months
Load (kips)
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Elongation (in)
Field Specimen 1
Field Specimen 2
Field Specimen 3
Control 1
Control 2
Control 3
Field Ave Strength
Field Peak Disp.
Control Ave Strength
Control Peak Disp.

MCBH Coastal – Open Crawl Connections
7 Months Exposure


MCBH Coastal - Open Crawl exposure (L5) - 7 Months
Load (kips)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Elongation (in)
Field Specimen 1
Field Specimen 2
Field Specimen 3
Control 1
Control 2
Control 3
Field Ave Strength
Field Peak Disp.
Control Ave Strength
Control Peak Disp.


Average Peak Strength - 7 Month exposure
Strength Ratio
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Control
MCBH Inland Exterior
MCBH Coast Open Crawl
Iroquois Coast Exterior
MCBH Coast Exterior
MCBH Coast Covered Crawl
MCBH Coast Ext 3M Open Crawl 4M


Average Displacement at Peak Load - 7 Months Exposure
Displacement Ratio
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Control
MCBH Inland Exterior
MCBH Coast Covered Crawl
MCBH Coast Open Crawl
Iroquois Coast Exterior
MCBH Coast Exterior
MCBH Coast Ext 3M Open Crawl 4M

Outline

- HUD project overview
- Field study
- Laboratory study
- Field observations
- Recommendations

Accelerated Laboratory Testing

- 1100 liter Cyclic corrosion chamber installed at UH structures laboratory.
- Cyclic testing options include salt-solution spray, drying and high humidity periods in cycles.
- Test connections identical to those stored in field enclosures.
- Relate level of corrosion to strength reduction
- Attempt to correlate with field observations

Cyclic Corrosion Chamber

Cyclic Routine

- Considered numerous industry standards (Salt spray, Auto industry, etc.)
- Require routine that simulates atmospheric conditions.
- Should produce the same ratio between corrosion rates for steel and zinc.

Research by Dr. Zhang

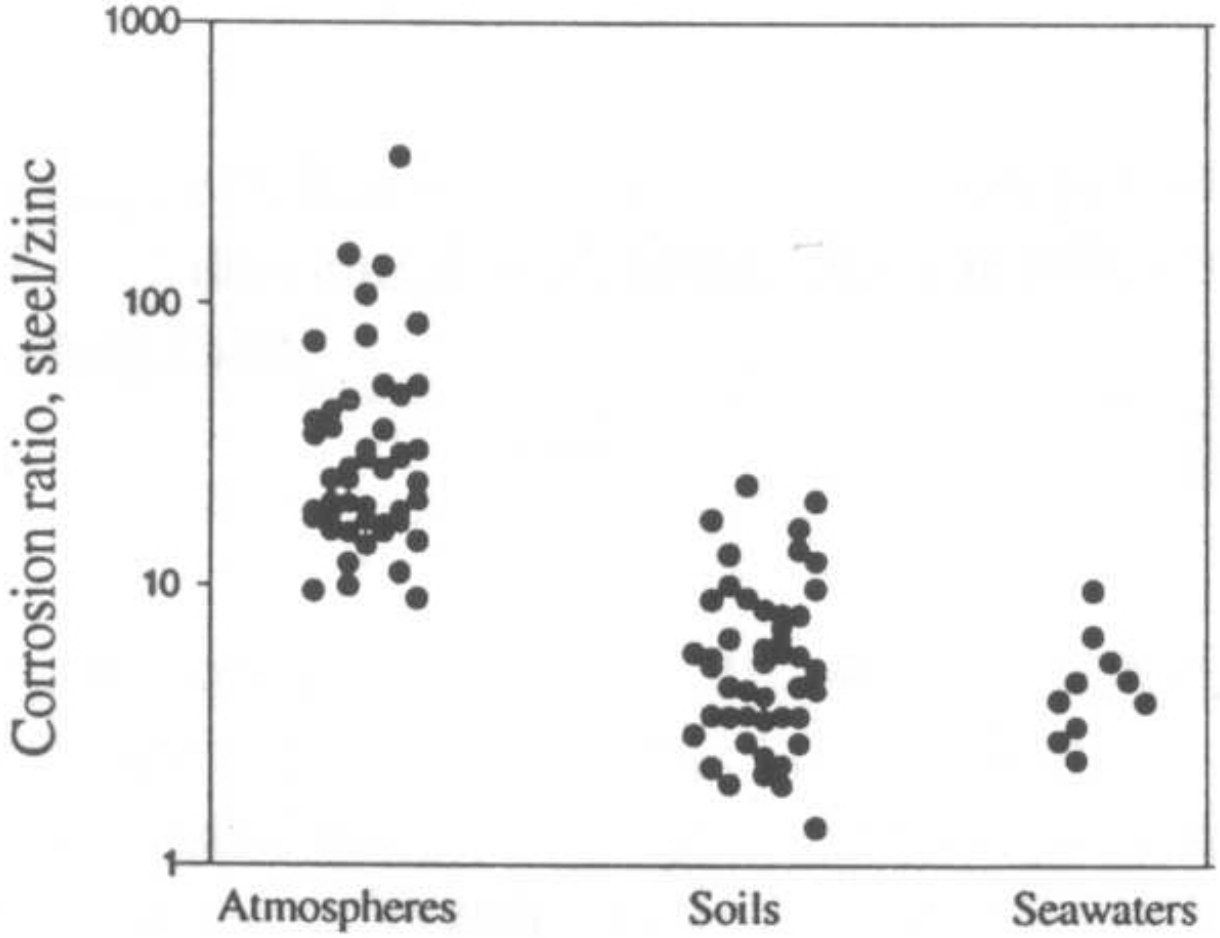


Figure 2 Corrosion ratios of steel/zinc in different natural corrosion environments

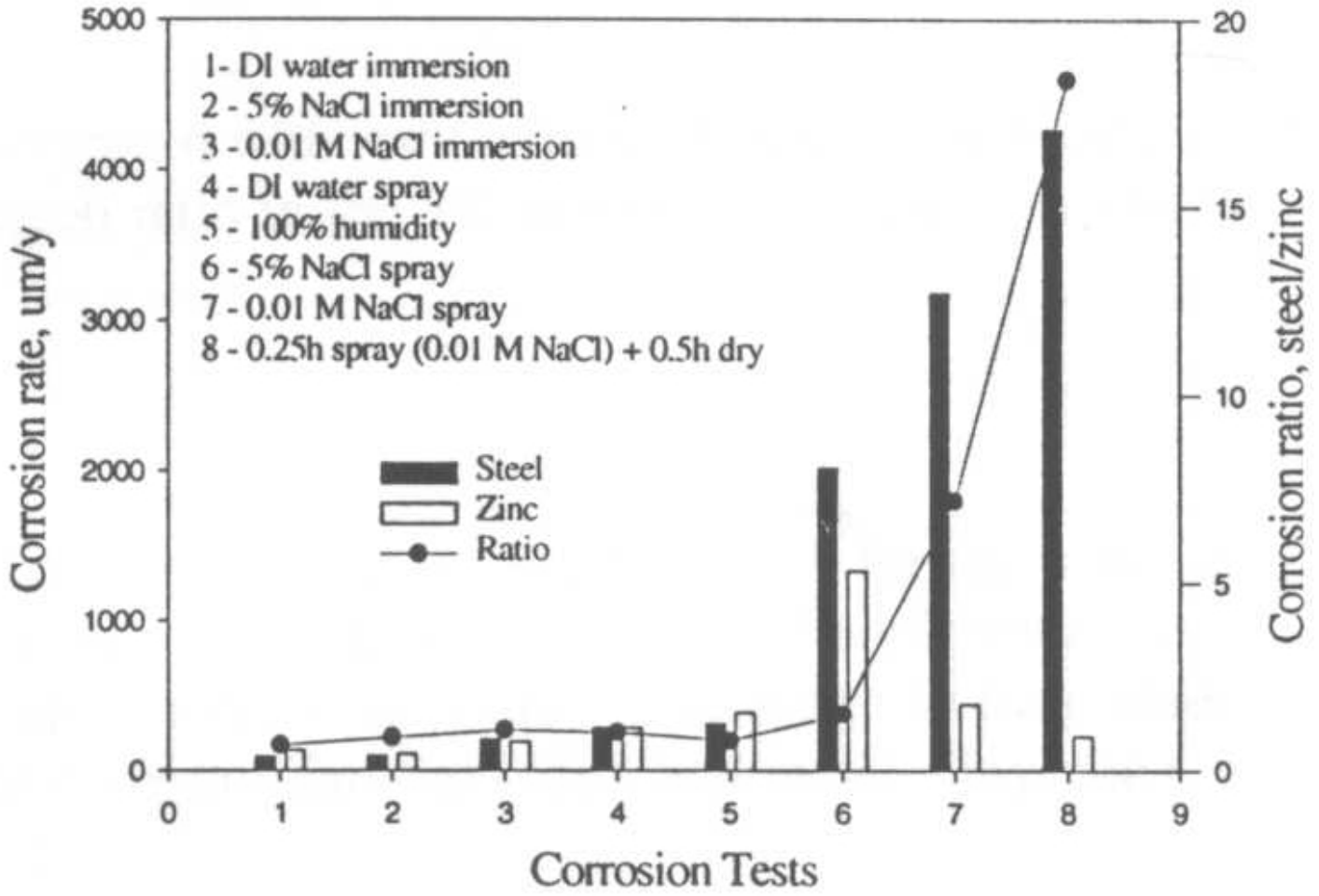
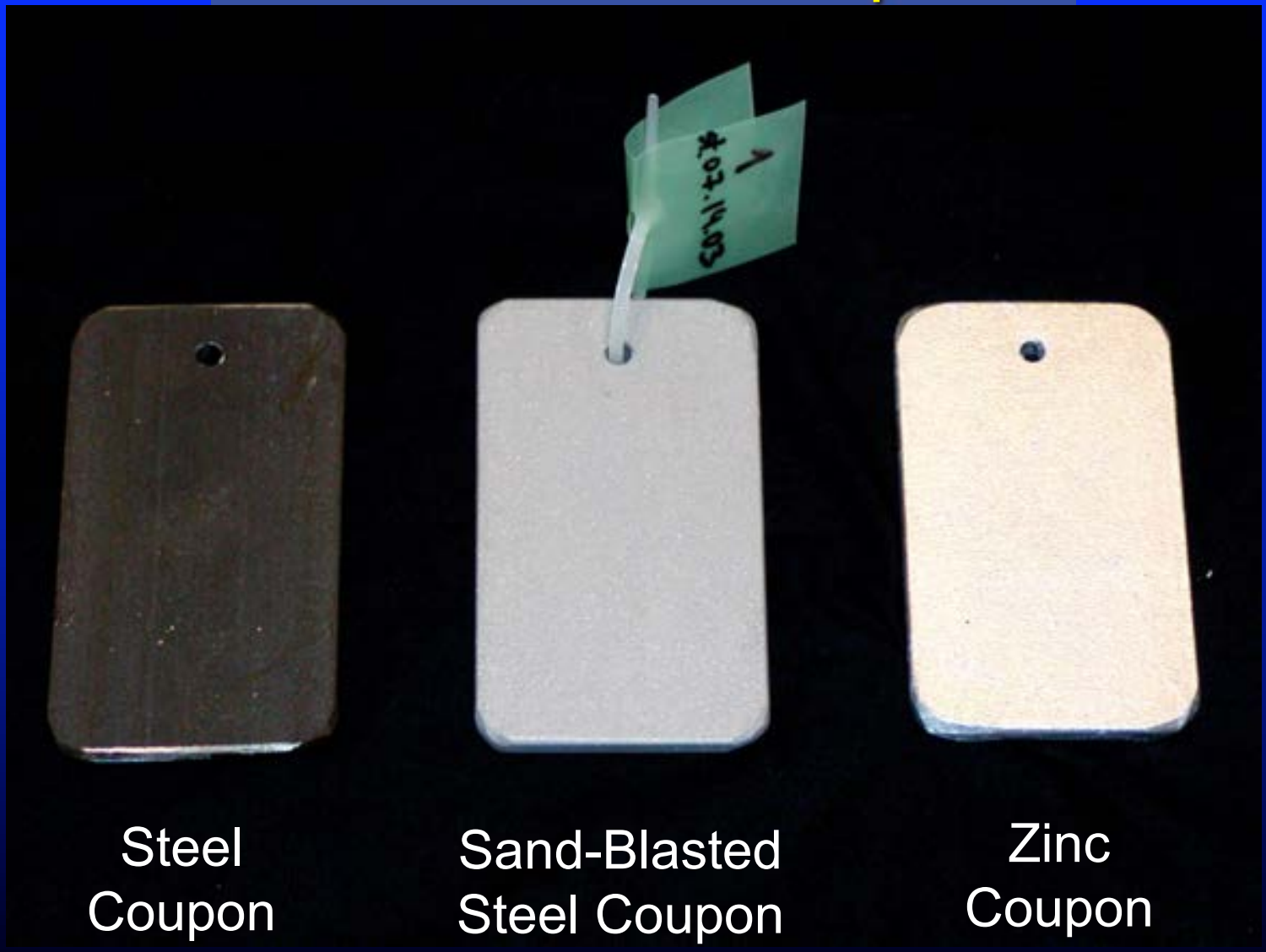


Figure 3 Corrosion rates of steel and zinc and their ratios in different corrosion tests

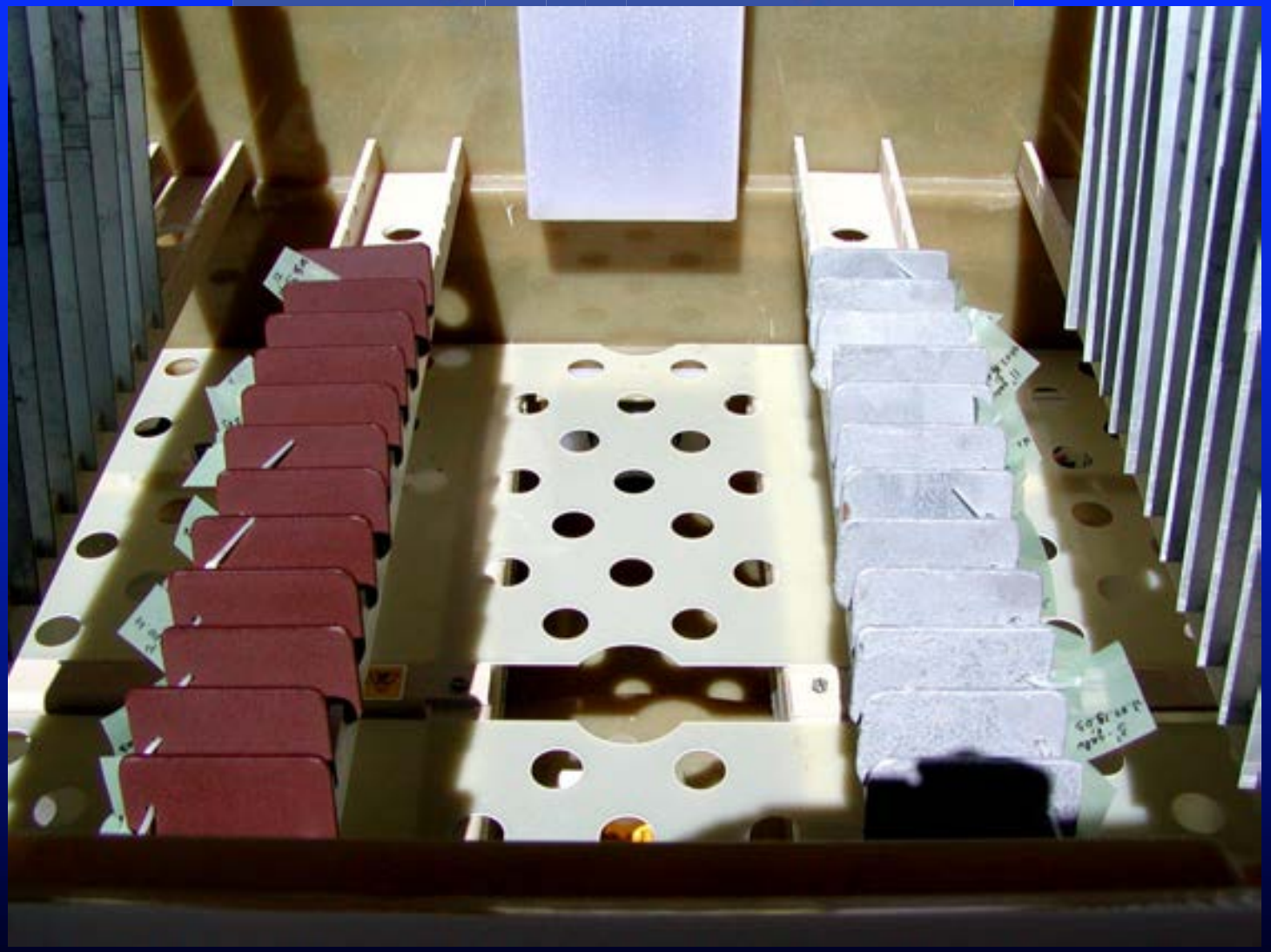
Cyclic Routine

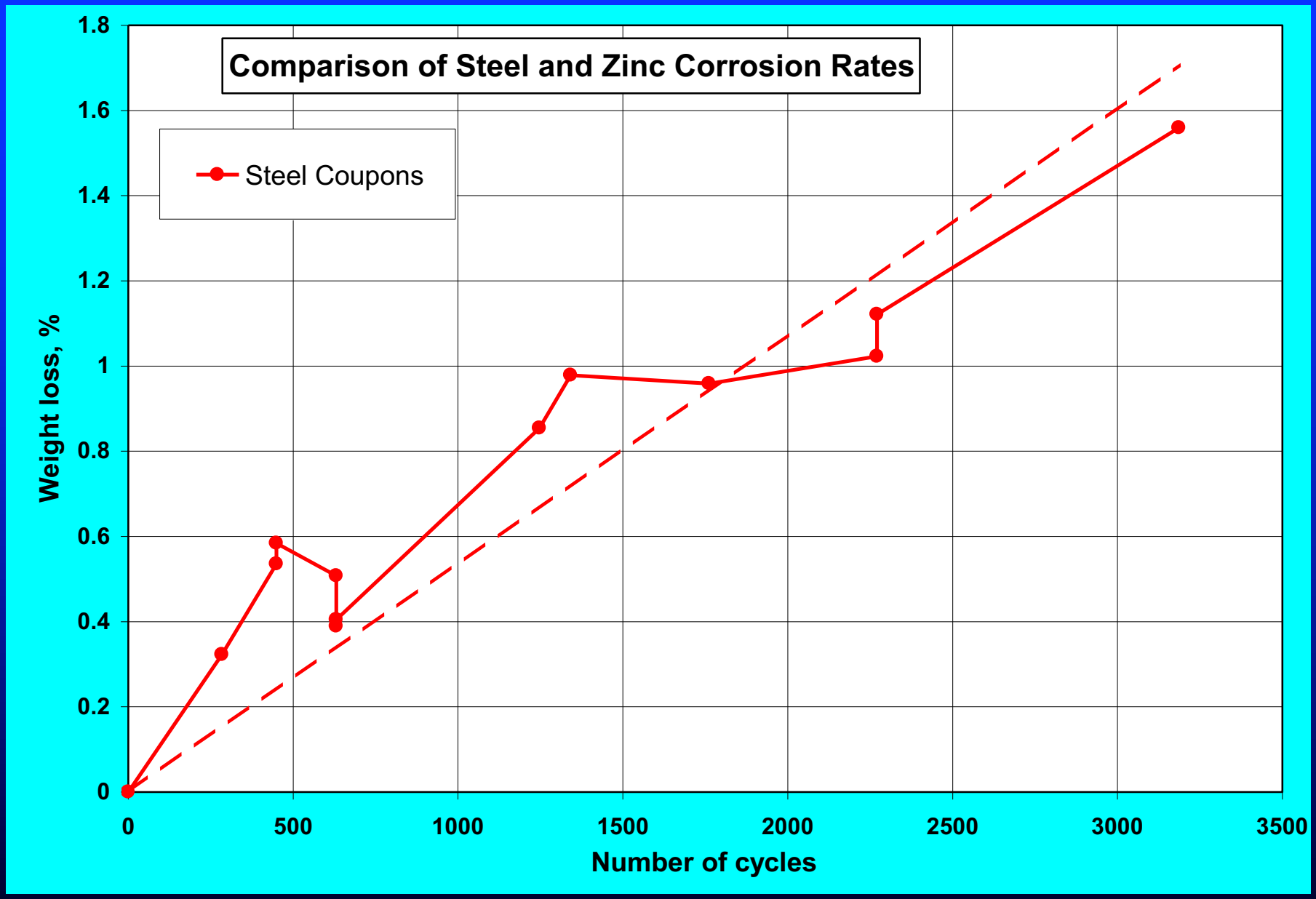
- Selected cyclic routine recommended by Dr. Zhang of Teck Cominco.
  - Weak salt water solution (0.08% NaCl)
  - Salt spray for 15 minutes at 35^{o} C
  - Drying for 30 minutes at 35^{o}C
  - Repeat
  - Best replicates 10:1 corrosion ratio for Steel:Zinc in atmospheric conditions

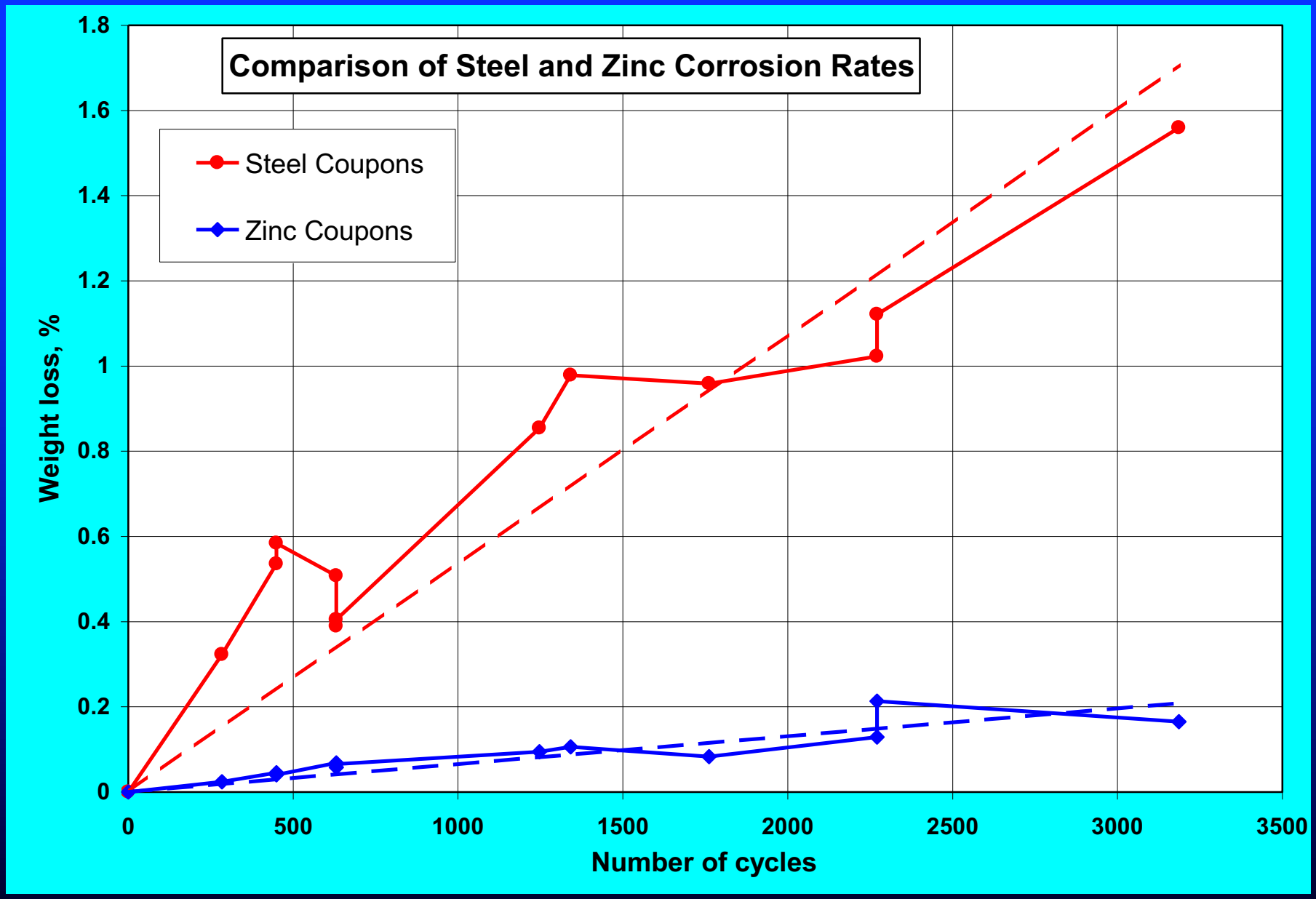
Steel and Zinc Coupons

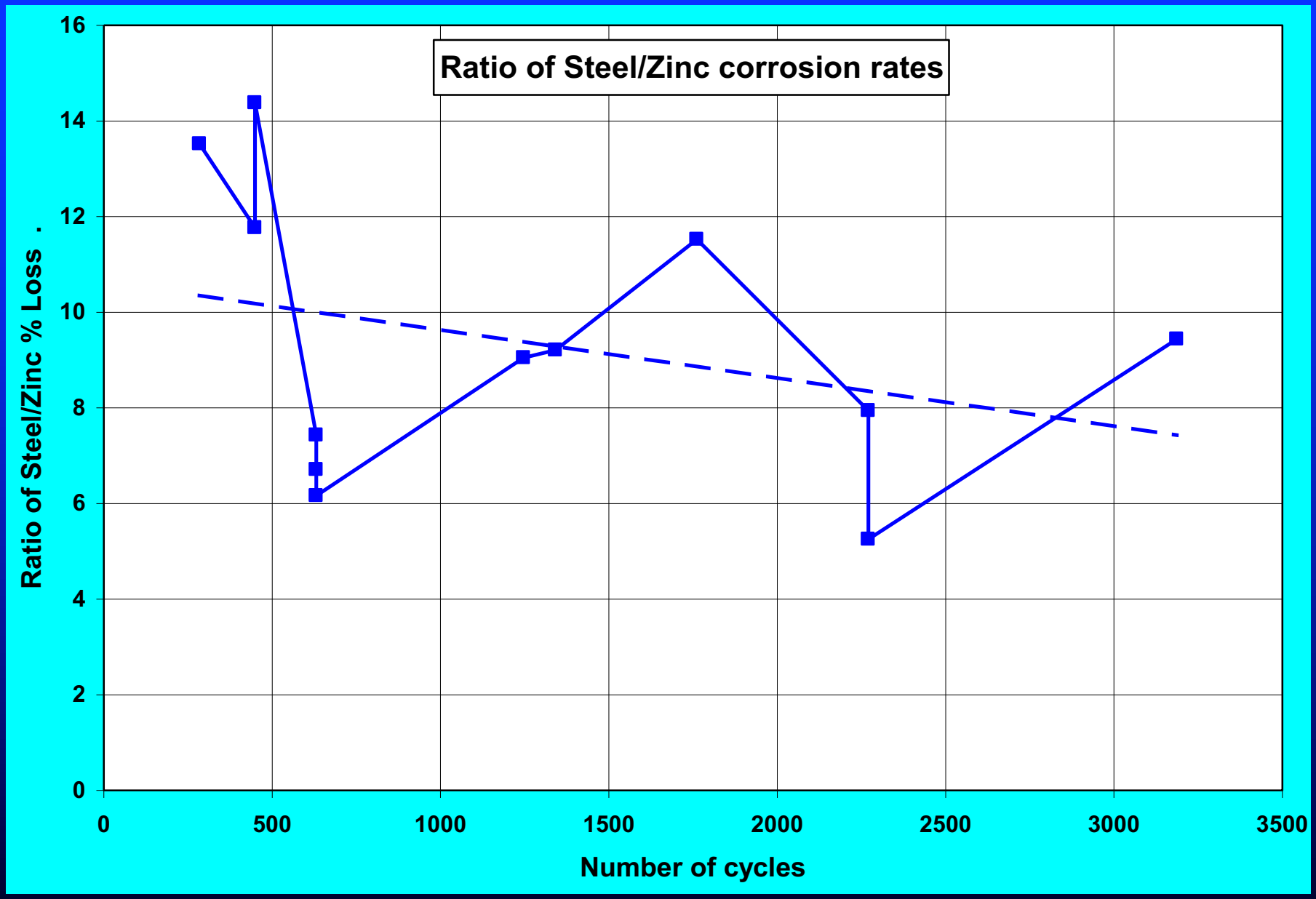


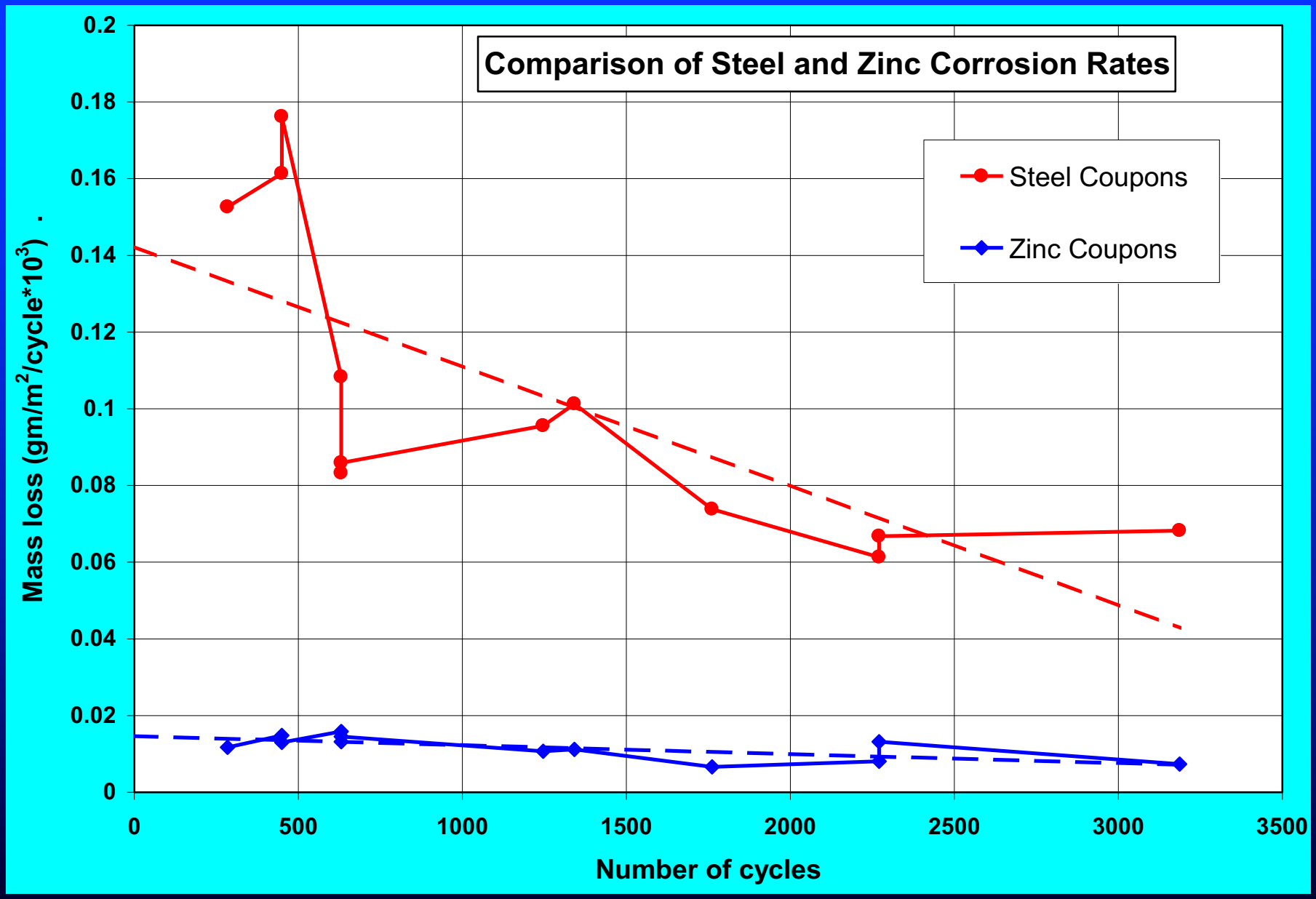
5 Days – 160 Cycles




Comparison of Steel and Zinc Corrosion Rates
Steel Coupons
Weight loss, %
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
500
1000
1500
2000
2500
3000
3500
Number of cycles


Comparison of Steel and Zinc Corrosion Rates
Steel Coupons
Zinc Coupons
Weight loss, %
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
3500
Number of cycles

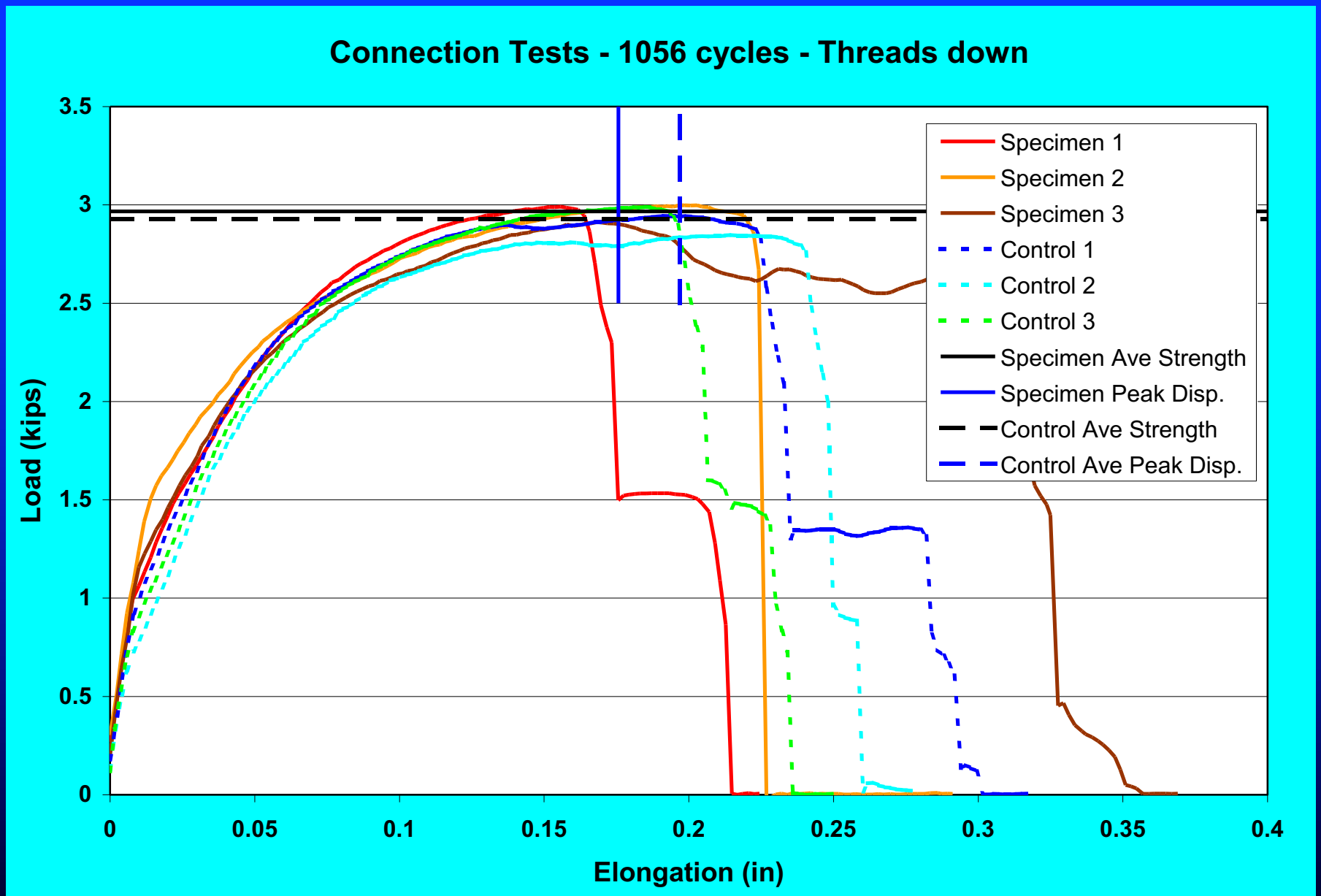

Ratio of Steel/Zinc corrosion rates
Ratio of Steel/Zinc % Loss .
Number of cycles
0
2
4
6
8
10
12
14
16
0
500
1000
1500
2000
2500
3000
3500

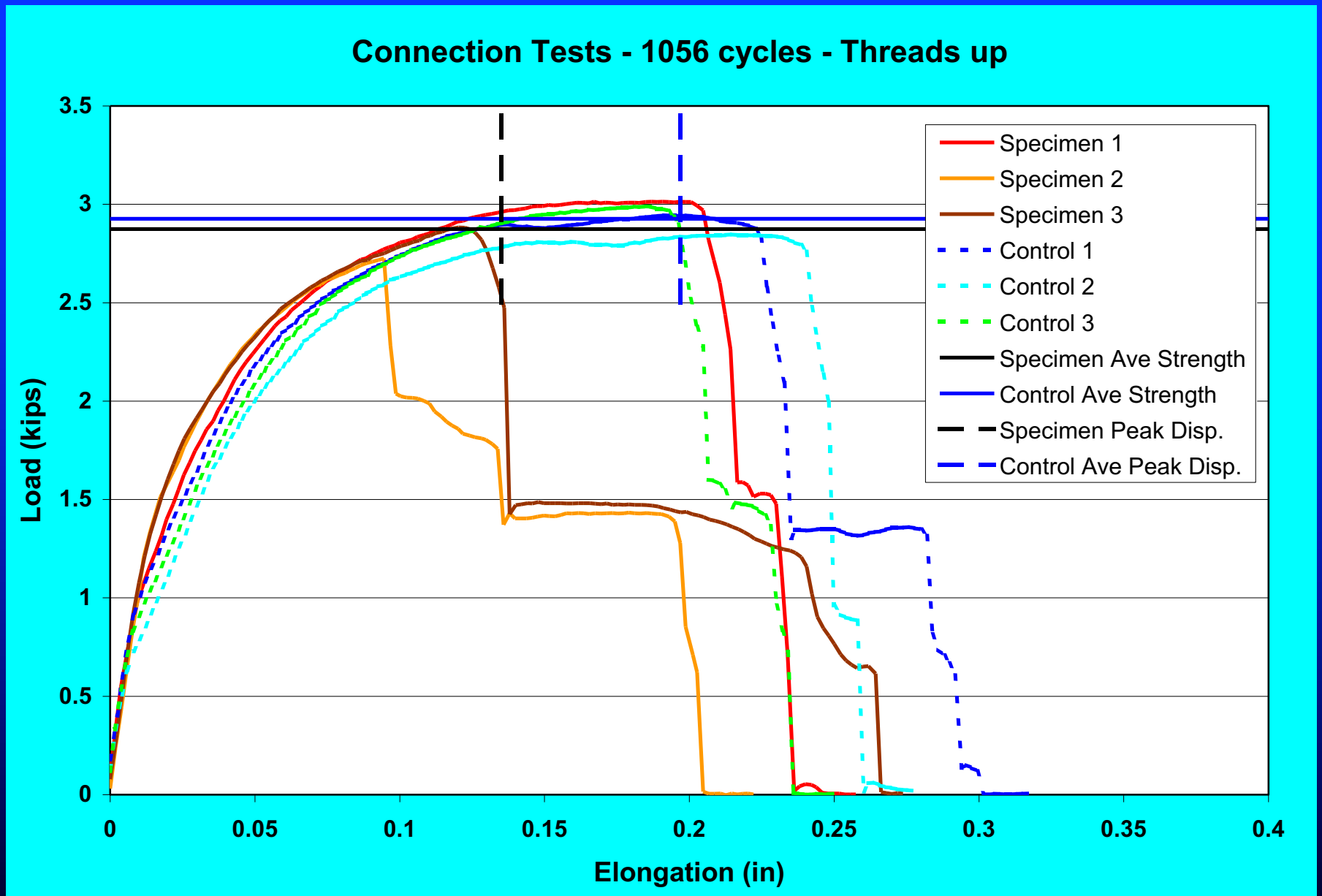

Comparison of Steel and Zinc Corrosion Rates
Steel Coupons
Zinc Coupons
Mass loss (gm/m2/cycle*10^3) .
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
500
1000
1500
2000
2500
3000
3500
Number of cycles

Connections after 1056 Cycles

Threads Down

Threads Up

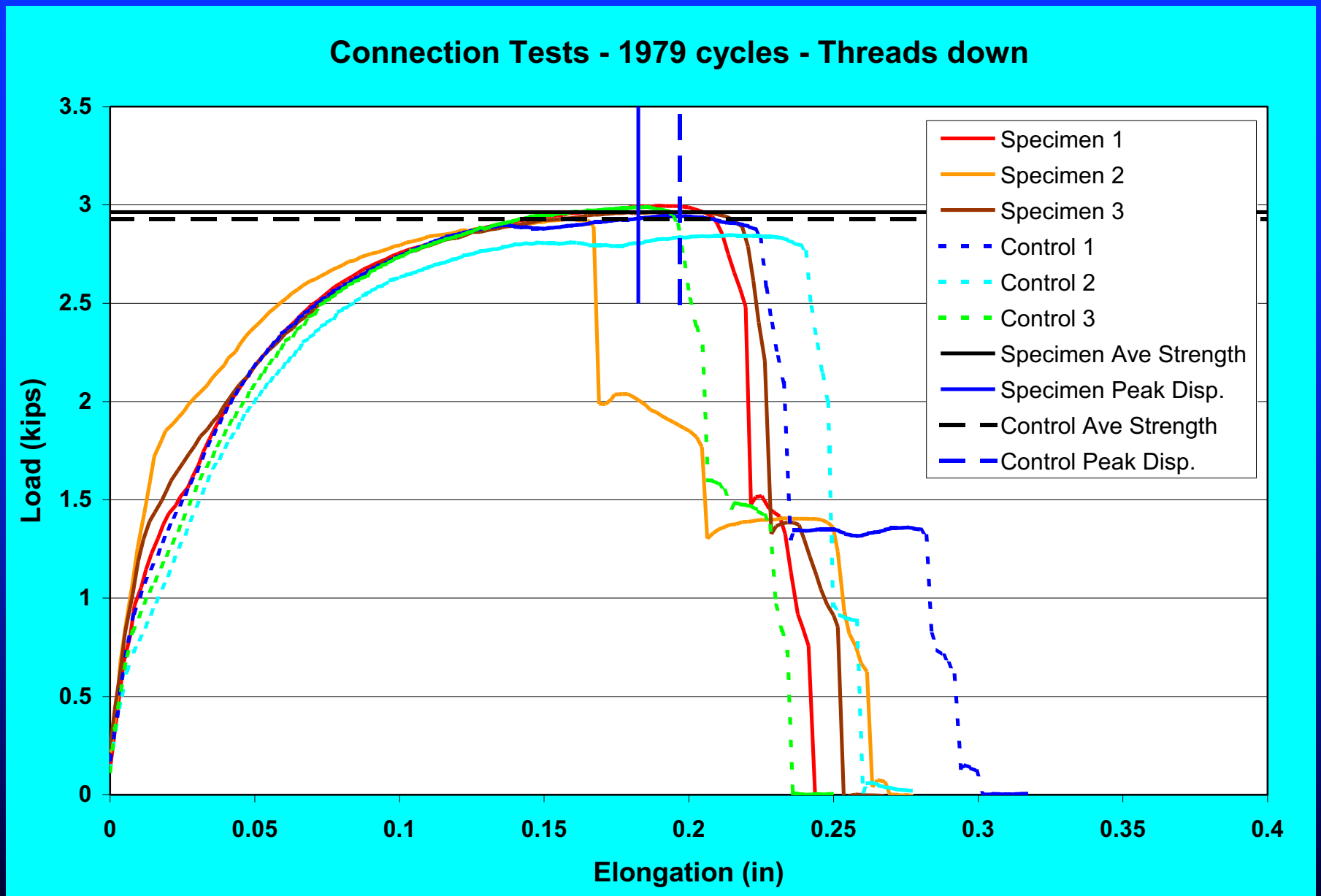

Connection Tests - 1056 cycles - Threads down
Load (kips)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Elongation (in)
Specimen 1
Specimen 2
Specimen 3
Control 1
Control 2
Control 3
Specimen Ave Strength
Specimen Peak Disp.
Control Ave Strength
Control Ave Peak Disp.

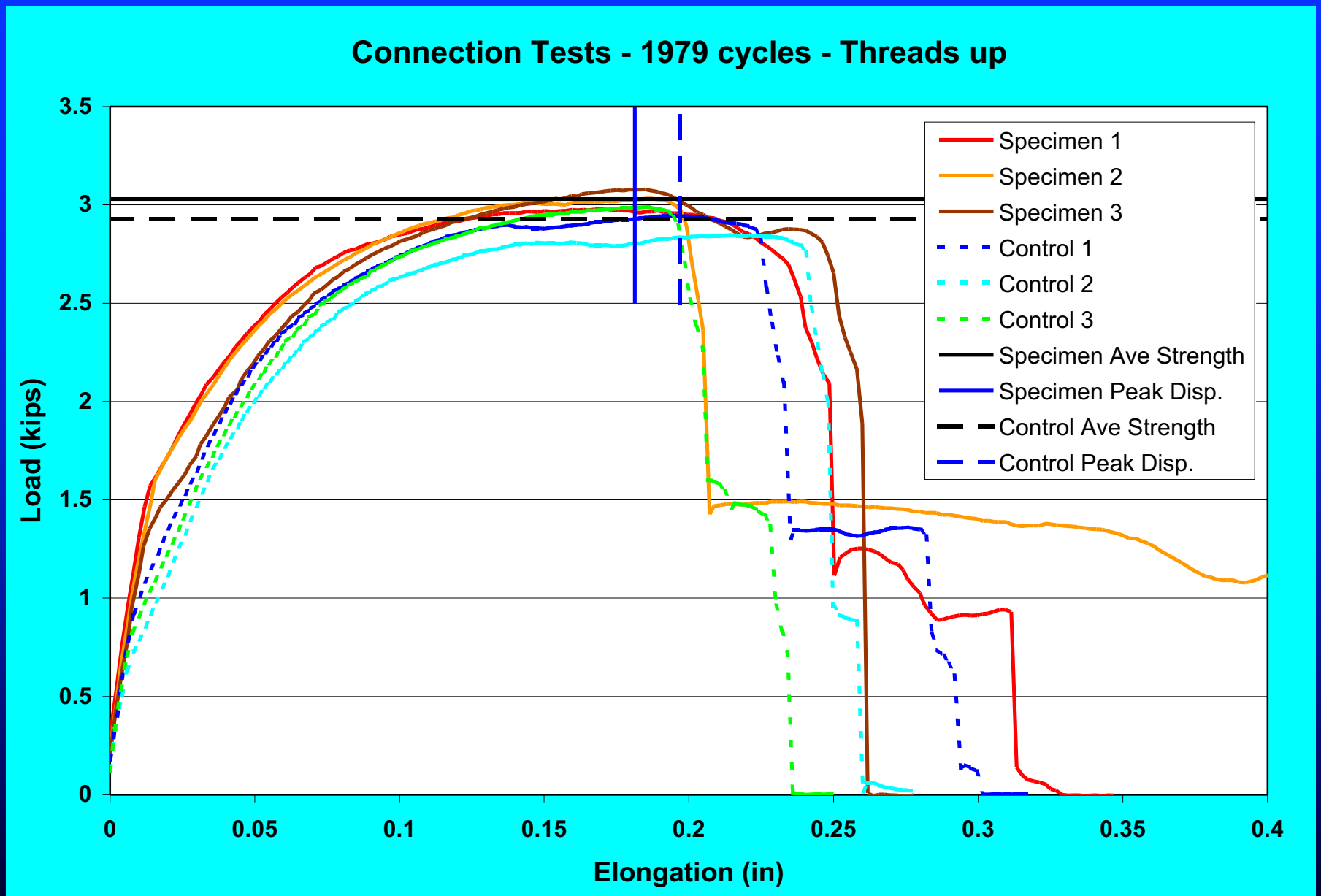

Connection Tests - 1056 cycles - Threads up
Load (kips)
Elongation (in)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Specimen 1
Specimen 2
Specimen 3
Control 1
Control 2
Control 3
Specimen Ave Strength
Control Ave Strength
Specimen Peak Disp.
Control Ave Peak Disp.

Connections after 1979 Cycles

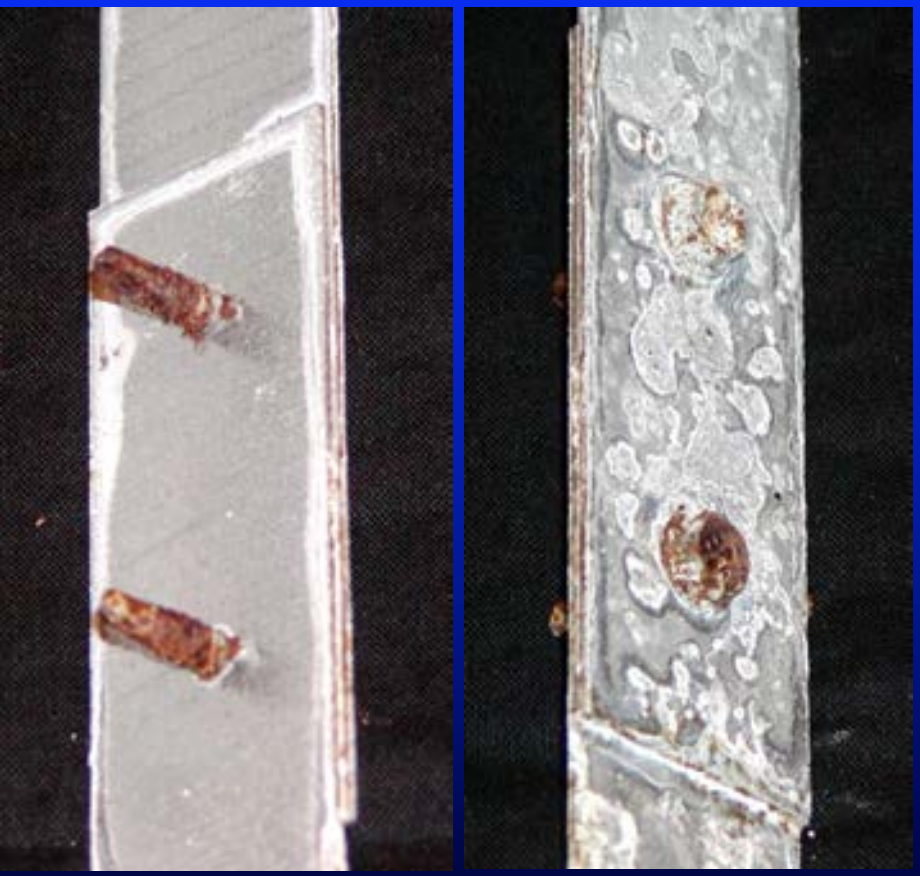
Threads Down

Threads Up

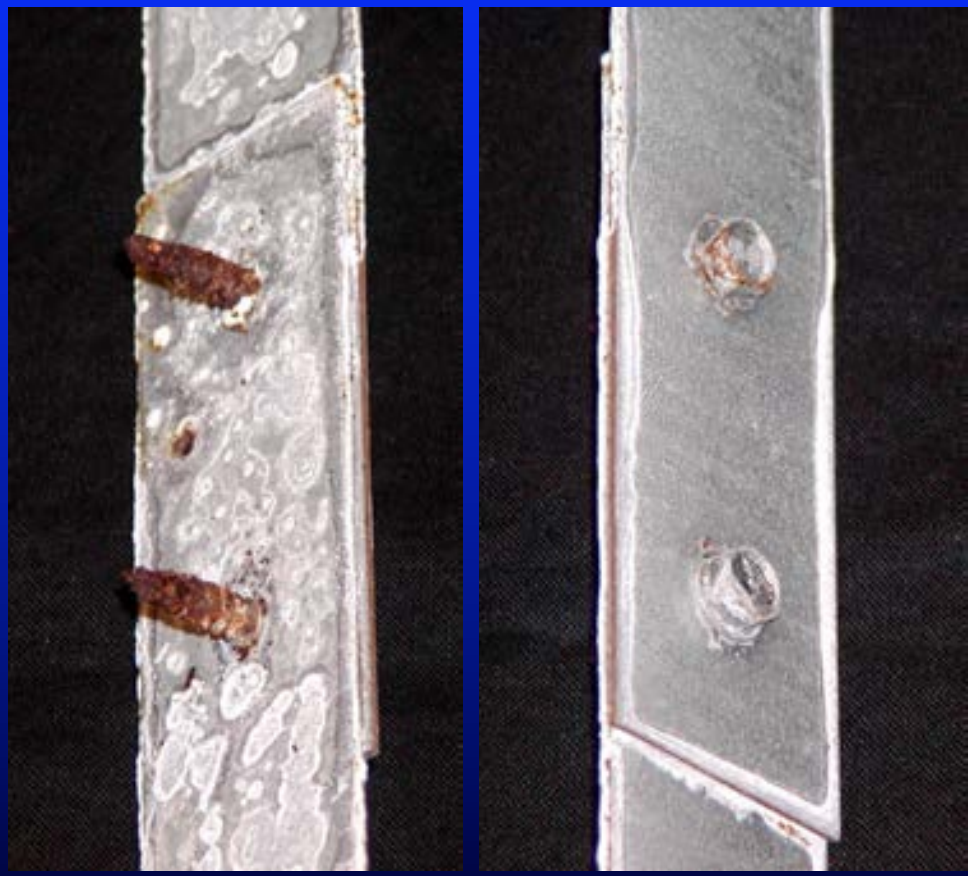

Connection Tests - 1979 cycles - Threads down
Load (kips)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Elongation (in)
Specimen 1
Specimen 2
Specimen 3
Control 1
Control 2
Control 3
Specimen Ave Strength
Specimen Peak Disp.
Control Ave Strength
Control Peak Disp.


Connection Tests - 1979 cycles - Threads up
Load (kips)
Elongation (in)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Specimen 1
Specimen 2
Specimen 3
Control 1
Control 2
Control 3
Specimen Ave Strength
Specimen Peak Disp.
Control Ave Strength
Control Peak Disp.

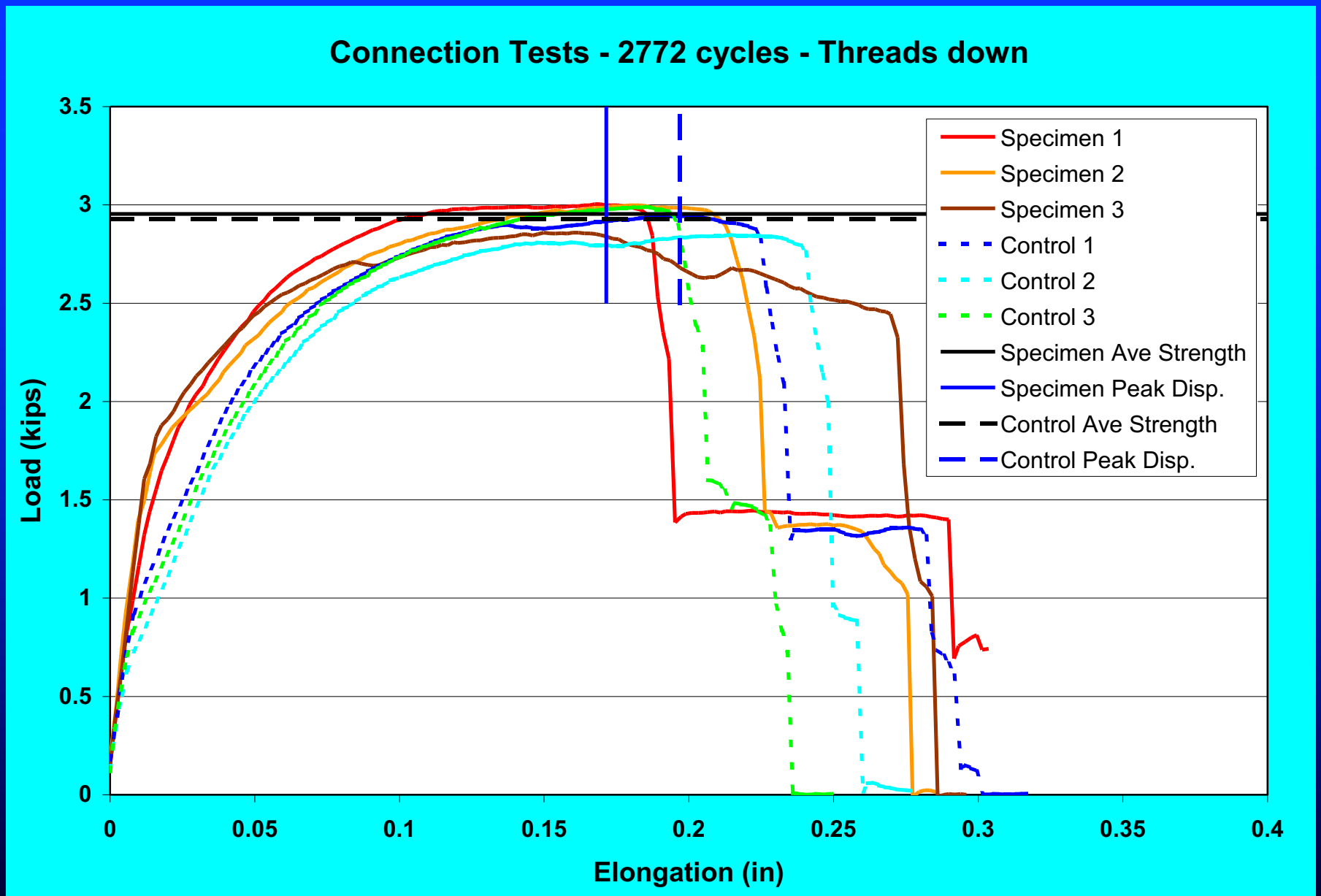
Connections after 2772 Cycles

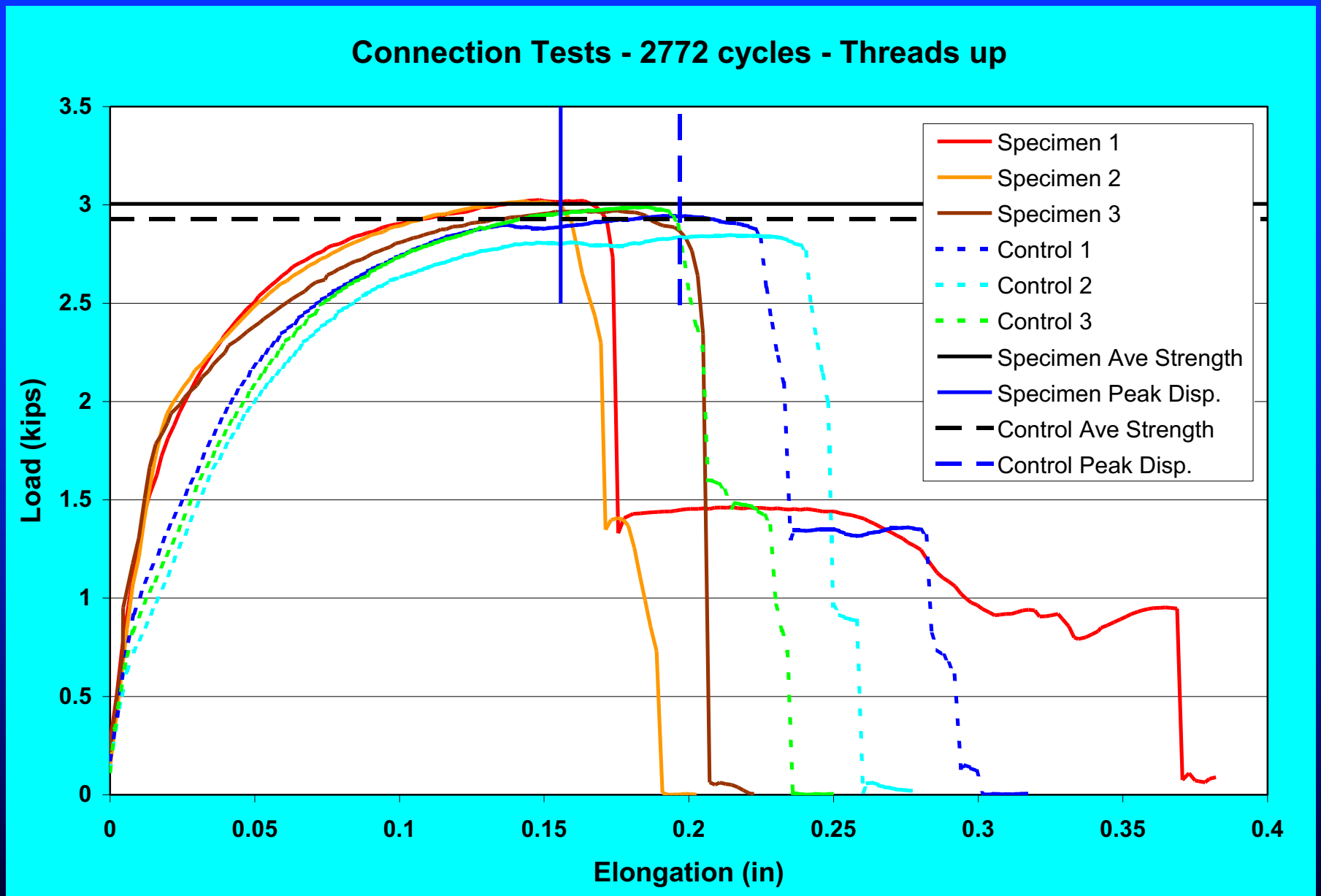


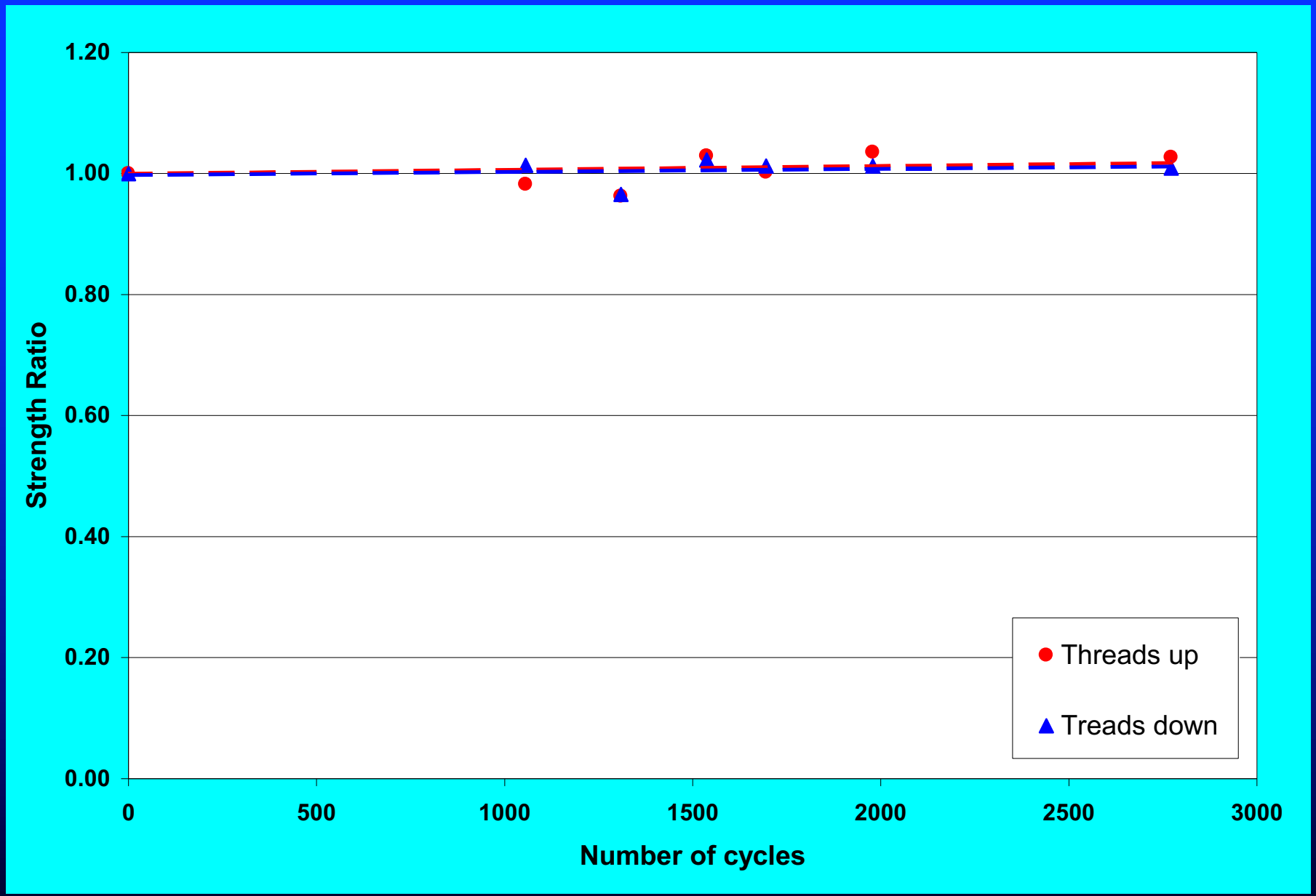
Threads Down

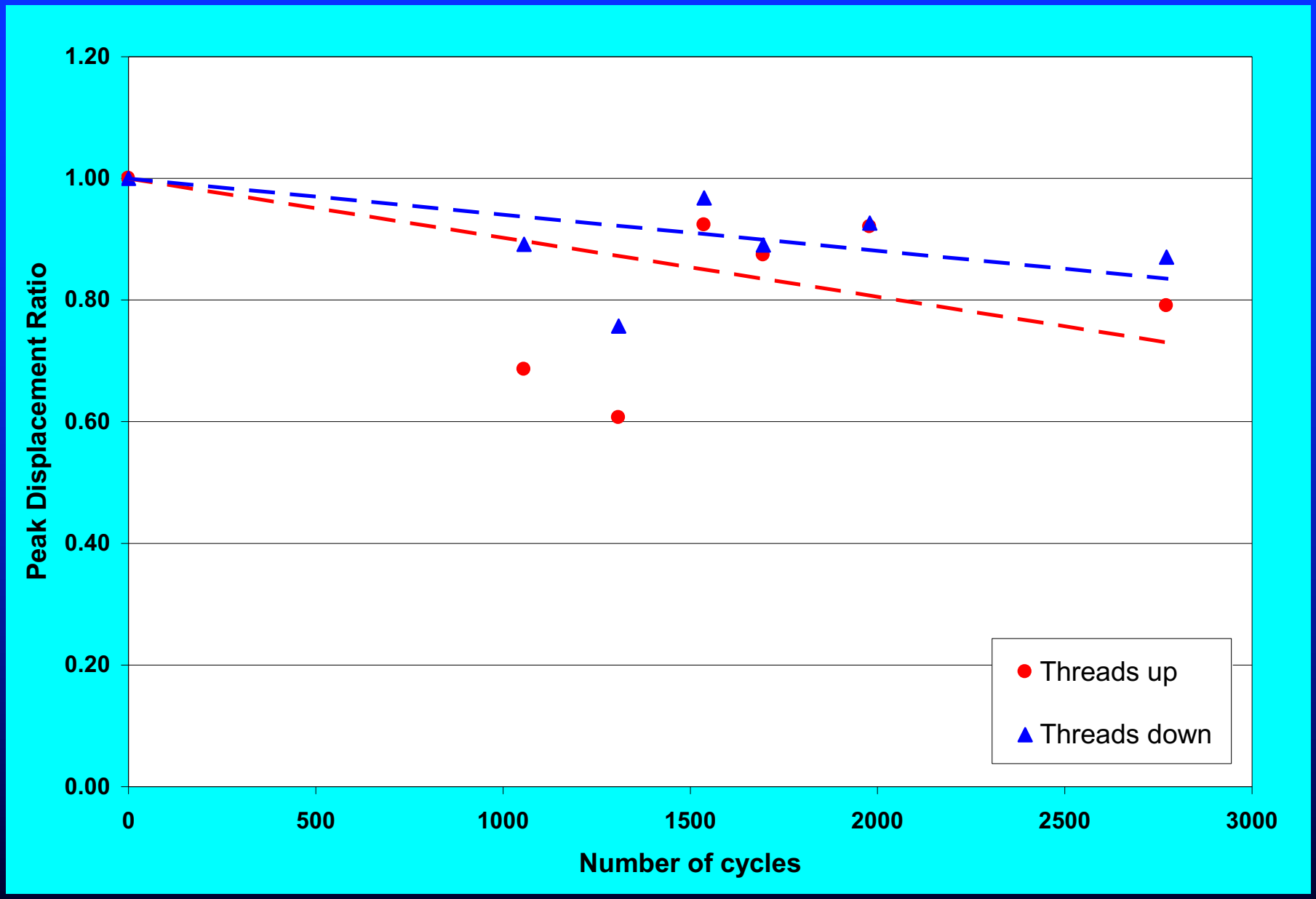


Threads Up

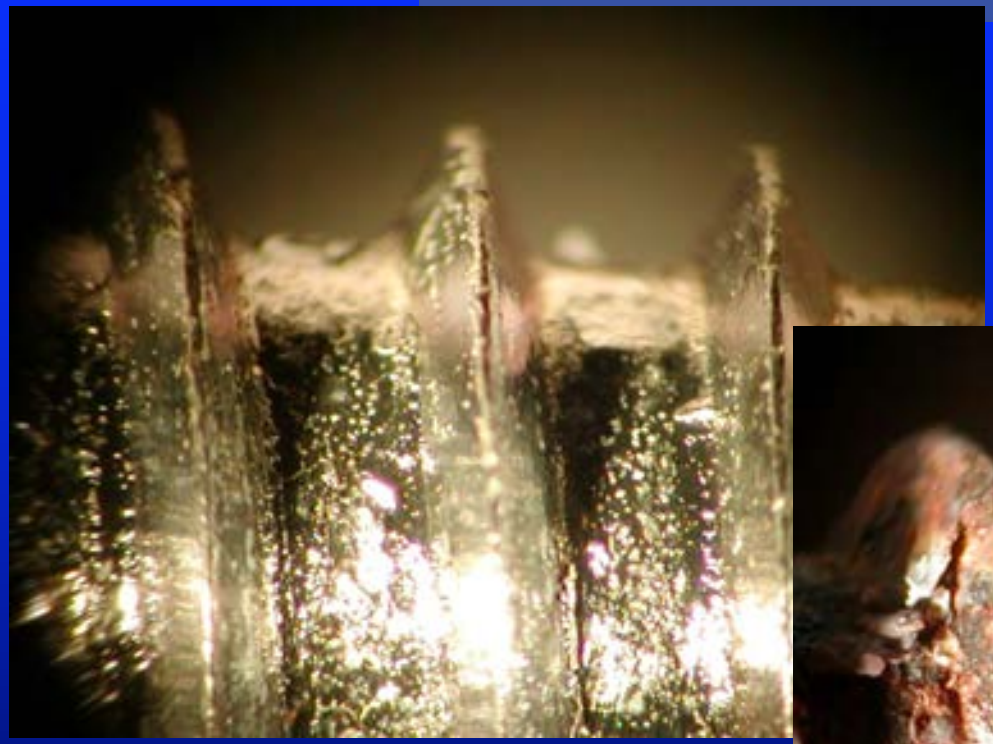

Connection Tests - 2772 cycles - Threads down
Load (kips)
Elongation (in)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Specimen 1
Specimen 2
Specimen 3
Control 1
Control 2
Control 3
Specimen Ave Strength
Specimen Peak Disp.
Control Ave Strength
Control Peak Disp.


Connection Tests - 2772 cycles - Threads up
Load (kips)
Elongation (in)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Specimen 1
Specimen 2
Specimen 3
Control 1
Control 2
Control 3
Specimen Ave Strength
Specimen Peak Disp.
Control Ave Strength
Control Peak Disp.


1.20
1.00
0.80
0.60
0.40
0.20
0.00
Strength Ratio
0
500
1000
1500
2000
2500
3000
Number of cycles
Threads up
Treads down


1.20
1.00
0.80
0.60
0.40
0.20
0.00
Peak Displacement Ratio
0
500
1000
1500
2000
2500
3000
Number of cycles
Threads up
Threads down

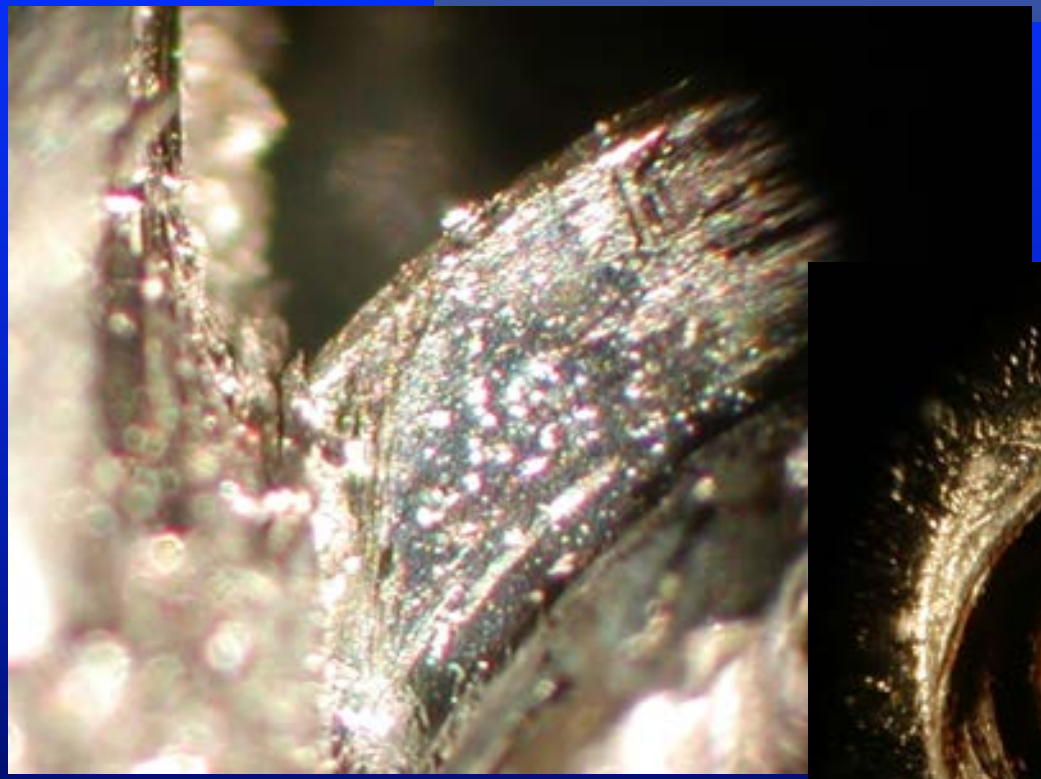
Microscopic Inspection



Screw Threads - Original

Screw Threads - 1537 Cycles

Microscopic Inspection



Failed Connection - Original

Failed Connection – 1537 Cycles

Preliminary Correlation with Field Sites

Location	Exposure	1 year exposure equivalent to	1000 cycles (1 month) equiv to
MCBH Coastal	Exposed crawl space	1500 cycles	8 months
	Vented attic Vented Wall	500 cycles	2 years
	Sealed crawl space or walls	250 cycles	4 years
MCBH Inland Iroquois Coastal Iroquois Inland	Exposed crawl and vented attic	250 cycles	4 years
	Sealed crawl space and walls	< 250 cycles	> 4 years
Wheeler AAF	All conditions	< 250 cycles	> 4 years

Outline

- HUD project overview
- Field study
- Laboratory study
- Field observations
- Recommendations

Visual Inspection at Field Sites

- Inspection:
  - Crawl Space Framing – Posts and Cripple Wall
  - Floor Framing – Exposed and enclosed
  - Wall Framing – With or without vapor barrier
  - Roof Framing – Vented attic
- Timeline (MCBH Enclosures):

• Panel Construction -	June 2001	
• Enclosure Constr. -	Nov-Dec 2001	Start
• First Inspection -	April 2002	5 Months
• Second Inspection -	Sept. 2002	10 Months
• Third Inspection -	March 2003	16 Months
• Coupon Installation -	August 2003	21 Months
• Fifth Inspection -	March 2004	28 Months

Observations at MCBH Coastal

Crawl Space

Exposed and Covered Floor Framing

Hardy Board lap-siding without vapor barrier

Hardy Board lap-siding with vapor barrier

Plywood sheathing and vinyl siding

Vented Attic

Observations at MCBH Inland

Observations at MCBH Inland

Observations at MCBH Inland

28 Months

56 Months

Observations at MCBH Inland

Observations at MCBH Inland

28 Months

56 Months

Observations at MCBH Inland

28 Months

56 Months

Observations at MCBH Inland

28 Months

56 Months

Observations at MCBH Inland

Observations at MCBH Inland

Observations at MCBH Inland

Observations at MCBH Inland

Observations at MCBH Coastal

Observations at MCBH Coastal

Observations at MCBH Coastal

Observations at MCBH Coastal

Observations at MCBH Coastal

Covered Crawl Space

56 Months

Observations at MCBH Coastal

Observations at MCBH Coastal

Hardie Board without Vapor Barrier

28 Months

56 Months

Observations at MCBH Coastal

Hardie Board without Vapor Barrier

Observations at MCBH Coastal

Hardie Board with Vapor Barrier

28 Months

56 Months

Observations at MCBH Coastal

Hardie Board with Vapor Barrier

14 Months

42 Months

Observations at MCBH Coastal

Plywood without Vapor Barrier

28 Months

56 Months

Observations at MCBH Coastal

Plywood without Vapor Barrier

14 Months

42 Months

Observations at MCBH Coastal

Outline

- HUD project overview
- Field study
- Laboratory study
- Field observations
- Recommendations

Recommendations

- Identify three exposure categories
  - Category A: Extreme exposure
  - Category B: Moderate exposure
  - Category C: Mild exposure
- Each building location assigned to one of these exposure categories based on
  - geographical location
  - surrounding features
  - meteorological records

Definitions

- Distance from Shoreline
  - Straight line distance, perpendicular to coast
- Onshore and Offshore Wind
  - Refers to predominant wind direction. If unknown, assume “Onshore Wind”.
- Shielded
  - Refers to presence of significant vegetation and/or structures, at least as tall as the proposed building, located between the coast and the proposed site
- Unshielded
  - Limited or no vegetation or structures between coast and proposed site

Category Assignment

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
$L \leq 200$ m				
$200 \text{ m} < L \leq 500$ m				
$500 \text{ m} < L \leq 1000$ m				
$L > 1000$ m				

Category Assignment

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
L ≤ 200 m	**A**	**A**	**A**	
200 m < L ≤ 500 m	**A**			
500 m < L ≤ 1000 m				
L > 1000 m				

Category Assignment

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
L ≤ 200 m	**A**	**A**	**A**	
200 m < L ≤ 500 m	**A**			
500 m < L ≤ 1000 m			**C**	**C**
L > 1000 m	**C**	**C**	**C**	**C**

Category Assignment

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
L ≤ 200 m	**A**	**A**	**A**	**B**
200 m < L ≤ 500 m	**A**	**B**	**B**	**B**
500 m < L ≤ 1000 m	**B**	**B**	**C**	**C**
L > 1000 m	**C**	**C**	**C**	**C**

Category C Recommendations

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
L ≤ 200 m	A	A	A	B
200 m < L ≤ 500 m	A	B	B	B
500 m < L ≤ 1000 m	B	B	C	C
L > 1000 m	C	C	C	C

Category C Recommendations

- Mild Exposure - Inland locations
  - Standard industry construction practices should be followed.
  - Permanent exposure of CFS members or fasteners to ambient atmospheric conditions should be avoided.
  - Exposure to atmospheric conditions during construction should be limited to 6 months.
  - Attic and crawl space framing should be inspected regularly for signs of corrosion. These inspections should be performed at least once every 5 years.

Category B Recommendations

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
L ≤ 200 m	A	A	A	B
200 m < L ≤ 500 m	A	B	B	B
500 m < L ≤ 1000 m	B	B	C	C
L > 1000 m	C	C	C	C

Category B Recommendations

- Moderate Exposure
  - No CFS members or fasteners should be permanently exposed to ambient atmospheric conditions.
  - Exposure to atmospheric conditions during construction should be limited. If such exposure is expected to exceed 4 months, protective measures should be taken to prevent chloride accumulation on the CFS members.
  - Attics can be vented, but framing members and fasteners in the attic space should be provided with additional protection through the use of increased zinc coating thickness or the addition of zinc rich coatings after fabrication.

Category B Recommendations

- Moderate Exposure (Cont.)
  - Attic framing should be inspected regularly for signs of corrosion. These inspections should be performed at least once every 5 years.
  - Protection for CFS framing and fasteners in exterior walls can be achieved by providing an enclosed wall cavity.
  - Protection of CFS framing and fasteners in interior walls and floor systems is provided effectively by gypsum board coverings on both sides of the wall cavity, and as a ceiling below elevated floor framing.

Category A Recommendations

Distance from Shoreline (m)	Site Characteristics			
	Onshore Wind		Offshore Wind	
	Unshielded	Shielded	Unshielded	Shielded
L ≤ 200 m	A	A	A	B
200 m < L ≤ 500 m	A	B	B	B
500 m < L ≤ 1000 m	B	B	C	C
L > 1000 m	C	C	C	C

Category A Recommendations

- Extreme Exposure
  - No CFS members or fasteners should be exposed to ambient atmospheric conditions.
  - Exposure to atmospheric conditions during construction should be limited. If such exposure is expected to exceed 2 months, protective measures should be taken to prevent chloride accumulation on the CFS members.
  - No CFS framing should be exposed in sheltered locations such as crawl spaces or the interior of garages, carports and other unfinished spaces.

Category A Recommendations

- Extreme Exposure (Cont.)
  - Attic spaces require particular attention because of the need for venting to prevent moisture accumulation and potential mold development.
    - the attic space can be designed as a sealed environment with insulation placed directly under the roof sheathing (a.k.a. cathedral ceiling), and the area underneath designed as a conditioned space.
    - attic venting, particularly on the coastal elevation, can be kept to the minimum permitted by the applicable building code, while extra protection can be provided for the framing members and fasteners in the attic space through increased galvanizing thickness and/or the addition of zinc rich coatings after fabrication.
  - Attic framing should be inspected regularly for signs of corrosion. These inspections should be performed at least once every 2 years.

Category A Recommendations

- Extreme Exposure (Cont.)
  - Protection for CFS framing and fasteners in exterior walls can be achieved by providing an enclosed wall cavity.
    - All openings, window and door framing, service penetrations, etc. must be sealed so as to prevent airflow into the wall cavity.
    - The top of the wall must be sealed from any vented attic space above.
  - Protection of CFS framing and fasteners in interior walls and floor systems can be provided by gypsum board on both sides of the wall cavity, and as a ceiling below floor framing.
  - Consideration should be given to increasing the thickness of galvanizing on CFS members and fasteners.

MCBH Housing

MCBH Housing

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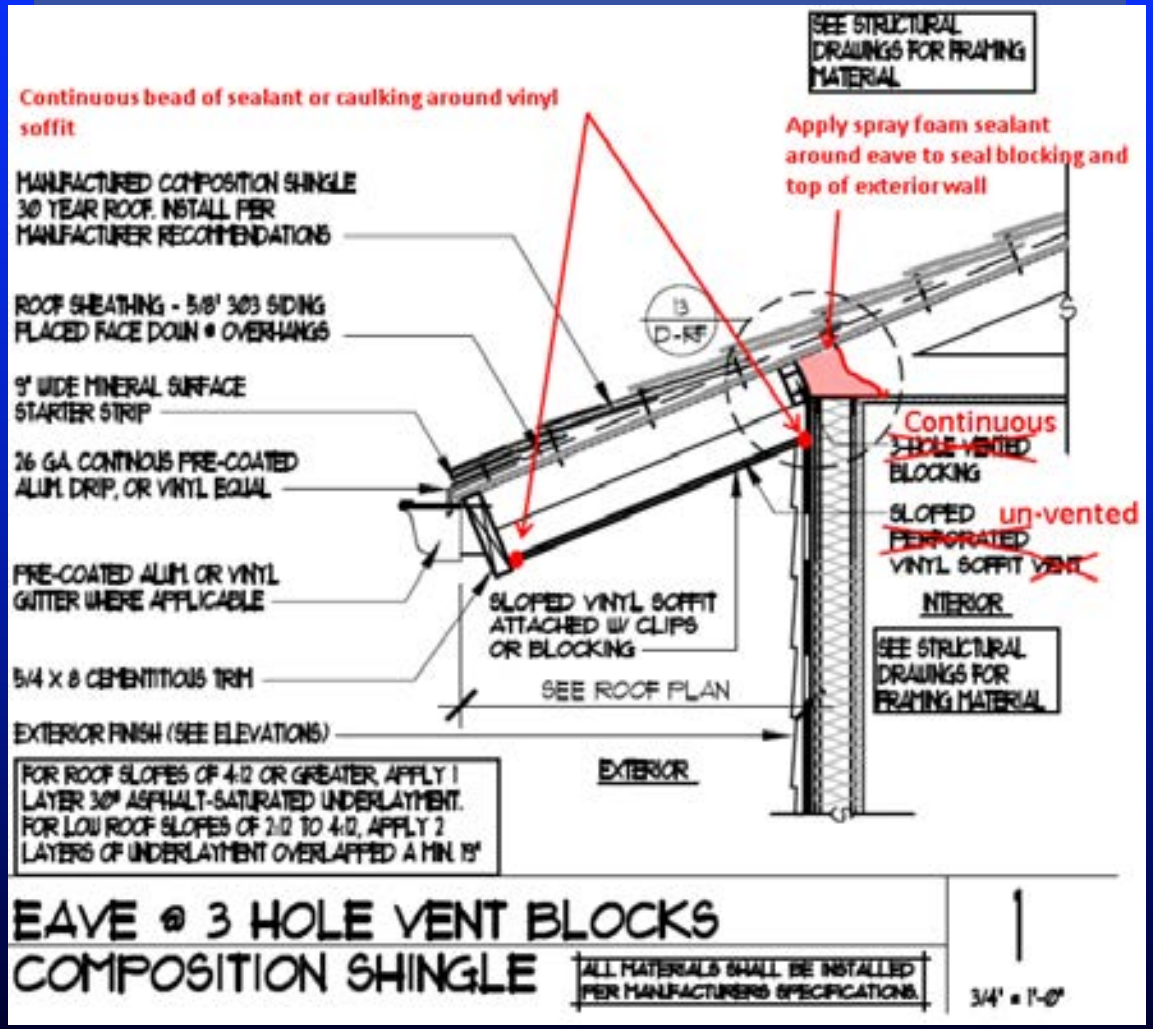
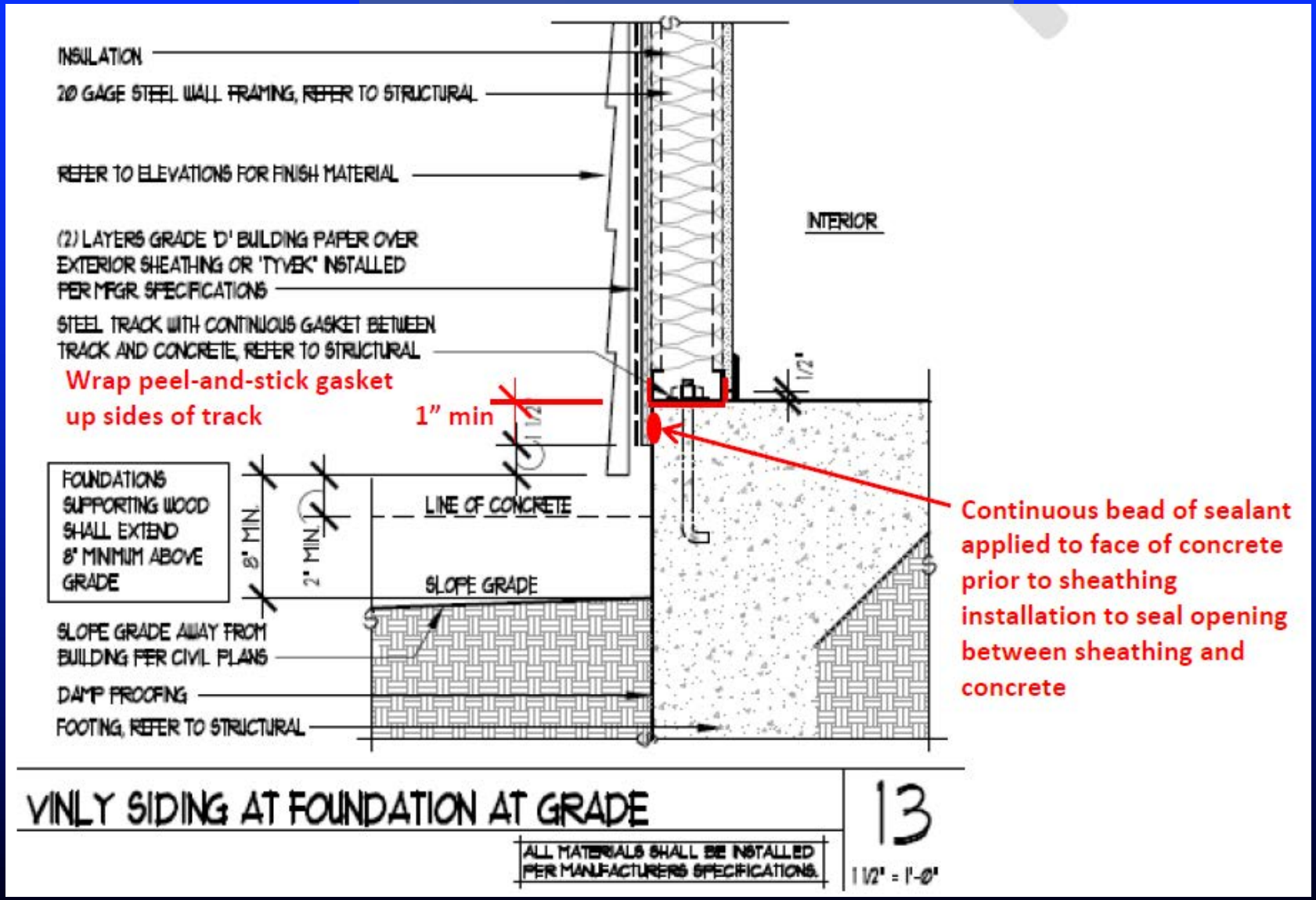
Sealed Conditioned Attics



Minimized Venting of un-conditioned Attics

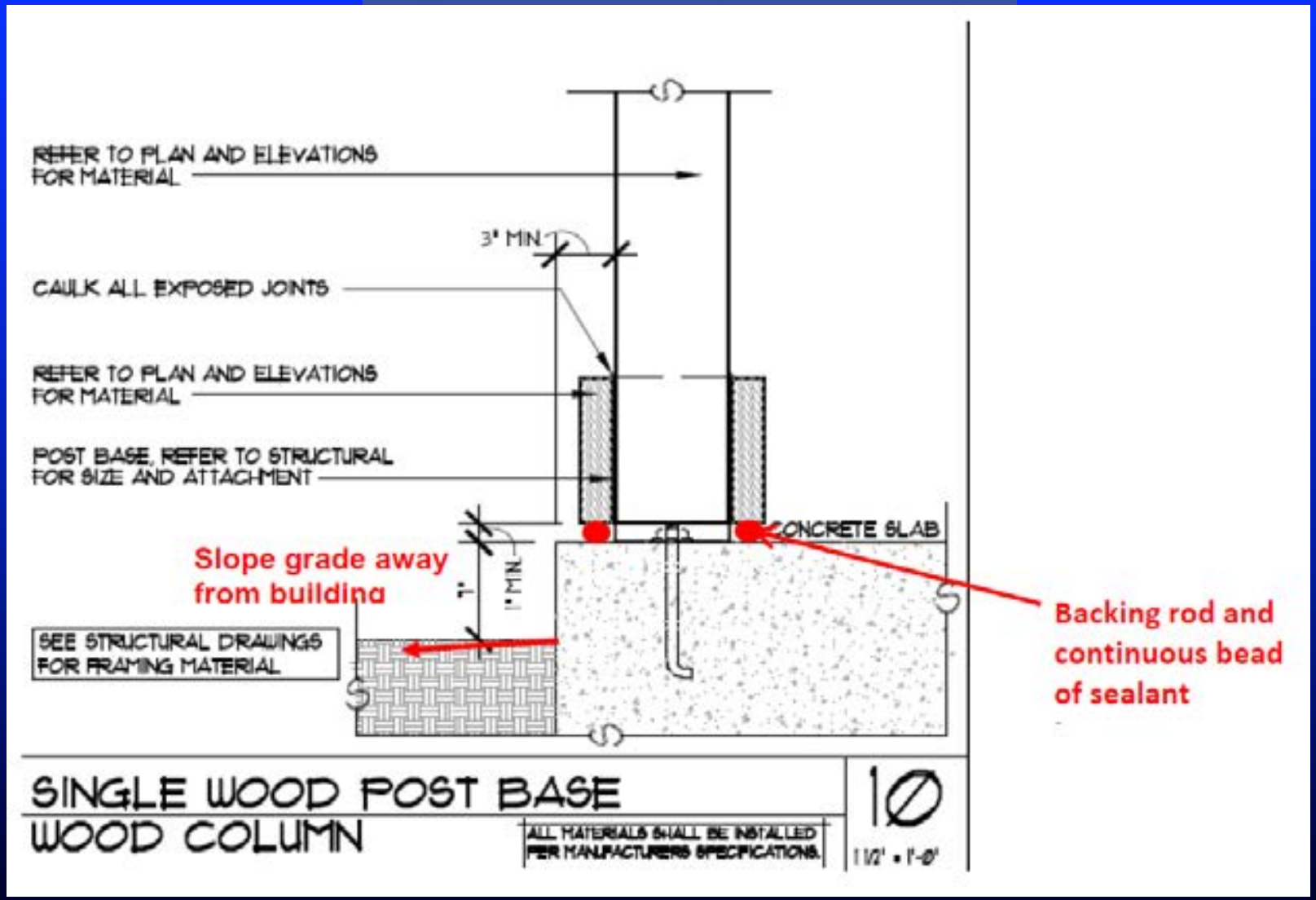
Seal Exterior Walls



Seal Exterior Walls

Seal Exterior Walls

Lanai Post Details



Lanai Post Details

Holddowns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Any Questions?