Avoiding the Corrosion of Connectors and Fasteners in the Construction of Coastal Structures

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Credit: 2 PDH

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This course was adapted from the Federal Emergency Management Agency, Publication No. NFIP Technical Bulletin 8, "Corrosion Protection for Metal Connectors and Fasteners in Coastal Areas", which is in the public domain.

COURSE CONTENT

1- Introduction

This technical course explains the importance of using corrosion-resistant metal connectors and fasteners in the construction of coastal structures, areas using preservative-treated lumber, and any locations subject to contact with floodwater or windblown rain.

Post-disaster assessments of wood-framed buildings following natural hazard events such as high winds, floods, and earthquakes have revealed that structural failures frequently occur at connections rather than in framing members. In coastal areas, where higher moisture and humidity levels exist and buildings are exposed to salt spray, corroded metal connectors and fasteners have been observed to contribute to the loss of an adequate load path. The loss of an adequate load often results in damage to or failure of the structure. This technical course presents guidance on addressing and avoiding the corrosion of connectors and fasteners.

2- NFIP Regulations

An important National Flood Insurance Program (NFIP) objective is to protect buildings constructed in Special Flood Hazard Areas (SFHAs) from damage caused by flood forces. The SFHA, composed of Zones A and V, is the areal extent of the base flood shown on Flood Insurance Rate Maps (FIRMs) prepared by FEMA. The base flood is the flood that has a 1 percent chance of being equaled or exceeded in any given year (commonly called the "100-year flood").

The NFIP regulations are codified in Title 44 of the Code of Federal Regulations (CFR) Part 60. Specific to this Technical Bulletin, in coastal regions, corrosion-resistant connectors and fasteners are essential to maintaining a building's load paths and demonstrating compliance with 44 CFR Sections 60.3(a)(3) and 60.3(e)(4).

I-CODES AND ASCE

The International Codes (I-Codes) and the standard, ASCE 24, *Flood Resistant Design and Construction*, include requirements for metal connectors and fasteners used in coastal areas that are susceptible to salt spray to address metal corrosion.

Section 60.3(a)(3) is applicable to all SFHAs:

If a proposed building site is in a flood-prone area, all new construction and substantial improvements shall (i) be designed (or modified) and adequately anchored to prevent flotation, collapse, or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy, (ii) be constructed with materials resistant to flood damage, (iii) be constructed by methods and practices that minimize flood damages

Section 60.3(e)(4) is applicable to Coastal High Hazard Areas (Zone V):

… new construction and substantial improvements… [shall be] elevated on pilings and columns so that …(ii) the pile or column foundation and structure attached thereto is anchored to resist flotation, collapse and lateral movement due to the effects of wind and water loads acting simultaneously on all building components. Water loading values used shall be those associated with the base flood. Wind loading values used shall be those required by applicable State or local building standards.

NFIP REQUIREMENTS AND HIGHER REGULATORY STANDARDS

State and Local Requirements. State or local requirements that are more stringent than the minimum requirements of the NFIP take precedence. The Technical Bulletins and other FEMA publications provide guidance on the minimum requirements of the NFIP and describe best practices. Design professionals, builders, and property owners should contact local officials to determine whether more restrictive provisions apply to buildings or sites in question. All other applicable requirements of the State or local building codes must also be met for buildings in flood hazard areas.

Substantial Improvement and Substantial Damage. As part of issuing permits, local officials must review not only proposals for new construction but also for work on existing buildings to determine whether the work constitutes Substantial Improvement or repair of Substantial Damage. If the work is determined to constitute Substantial Improvement or repair of Substantial Damage, the buildings must be brought into compliance with NFIP requirements for new construction. Some communities modify the definitions of Substantial Improvements and/or Substantial Damage to be more restrictive than the NFIP minimum requirements.

For more information on Substantial Improvement and Substantial Damage, see FEMA P-758, *Substantial Improvement/Substantial Damage Desk Reference* (2010b), and FEMA 213, *Answers to Questions About Substantially Improved/ Substantially Damaged Buildings* (2018a).

Flood Damage-Resistant Materials. Guidance on the NFIP requirement regarding the use of building materials resistant to flood damage can be found in Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements.*

3- Other Regulations

In addition to complying with NFIP requirements, all new construction, Substantial Improvements, and repair of Substantial Damage must comply with applicable building codes and standards that have been adopted by States and communities.

The International Codes® (I-Codes®), published by the International Code Council® (ICC®) are a family of codes that includes the International Residential Code® (IRC®), International Building Code® (IBC®), International Existing Building Code® (IEBC®), and codes that govern the installation of mechanical, plumbing, fuel gas service, and other aspects of building construction. FEMA has deemed that the latest published editions of the I-Codes meet or exceed NFIP requirements for buildings and structures. Excerpts of the flood provisions of the I-Codes are available on FEMA's Building Code Resource webpage (http://www.fema.gov/building-code-resources).

3.1 International Residential Code

The IRC applies to one- and two-family dwellings and townhomes not more than three stories above grade plane, with certain limitations for high wind, high seismic, and high snow regions. The IRC requirements that are related to connectors and fasteners in coastal areas are summarized in Table 1.

Although Table 1 refers to selected requirements of the 2018 IRC and notes changes from the 2015 and 2012 editions, subsequent editions should include comparable requirements.

Table 1: Comparison of Select 2018 IRC and NFIP Requirements

Topic	Summary of Select 2018 IRC Requirements and Changes from 2015 and 2012 Editions	Comparison with NFIP Requirement
Fasteners and connectors	**Section R317.3.1 Fasteners for preservative-treated wood.** Requires all fasteners used for pressure-treated wood to be corrosion resistant. Specific requirements for connectors are outlined in the IRC. The coating type and weights of connectors shall either be as specified by the manufacturer or meet the minimum requirements as specified in the IRC. Exceptions to this requirement are outlined in the IRC. Change from 2015 to 2018 IRC: The need for staples to be stainless steel was added. Change from 2012 to 2015 IRC: No changes.	No NFIP requirement
Flood-resistant construction	**Section R322.1.2 Structural systems.** Requires that buildings and structures be designed and constructed to resist flood forces during a design flood event. This includes connecting structural systems and anchoring the building to resist flotation, collapse or permanent lateral movement during a design flood. Changes from 2015 to 2018 IRC: No change. Changes from 2012 to 2015 IRC: No change.	Equivalent to NFIP regulation in 44 CFR §§ 60.3(a)(3)(i) and (iii), and § 60.3(e)(4)
Flood damage-resistant materials	**Section R322.1.8 Flood-resistant materials.** Requires materials used below the required design flood elevation to be flood damage resistant in conformance with NFIP Technical Bulletin 2. Change from 2015 to 2018 IRC: No change. Change from 2012 to 2015 IRC: The need for wood to be pressure-treated, preservative-treated, or decay-resistant heartwood was deleted to clarify that the guidance in NFIP Technical Bulletin 2 is adequate to meet flood damage-resistant material requirements.	Equivalent to NFIP regulation in 44 CFR § 60.3(a)(3)(ii)

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3.2 International Building Code and ASCE 24

The flood provisions in the latest published editions of the IBC meet or exceed the NFIP requirements for buildings largely through reference to the standard ASCE 24, *Flood Resistant Design and Construction*, developed by the American Society of Civil Engineers (ASCE). The IBC applies to all applicable buildings and structures. While primarily used for buildings and structures other than dwellings within the scope of the IRC, the IBC may be used to design dwellings. The IBC and ASCE 24 requirements related to the use of corrosion-resistant fasteners (often used for maintaining a building load path), which are summarized in Table 2, are more specific than NFIP regulations and also apply to areas where the minimum elevation requirements are above the base flood elevation (BFE) by the incorporation of freeboard.

IBC AND ASCE COMMENTARIES

ICC publishes companion commentary for the IBC and ASCE publishes companion commentary for ASCE 24. Although not regulatory, the commentaries provide information and guidance that are useful in complying with, interpreting, and enforcing requirements.

Although Table 2 refers to selected requirements of the 2018 IBC and ASCE 24-14 (noting changes from 2015 and 2012 IBC and ASCE 24-05), subsequent editions should include comparable requirements.

Table 2: Comparison of Select 2018 IBC and ASCE 24-14 Requirements with NFIP Requirements

Topic	Summary of Select 2018 IBC/ASCE 24-14 Requirements and Changes from 2015 and 2012 IBC/ASCE 24-05	Comparison with NFIP Requirement
General design requirement	**2018 IBC, Section 1612.2 Design and construction.** Requires buildings and structures located in all delineated flood hazard areas to be designed and constructed in accordance with Chapter 5 of ASCE 7 *(Minimum Design Loads and Associated Criteria for Buildings and Other Structures)* and ASCE 24. Change from 2015 to 2018 IBC: Section renumber from 1612.4 to 1612.2. Change from 2012 to 2015 IBC: Applies to coastal high hazard area requirements in Coastal A Zones, if delineated.	For Zones A and V, equivalent to NFIP 44 CFR § 60.3 For Coastal A Zones, more restrictive than the NFIP since the NFIP does not define Coastal A Zones
Fasteners and connectors for preservative-treated wood	**2018 IBC, Section 2304.10.5 Fasteners and connectors in contact with preservative-treated and fire-retardant-treated wood.** Requires all fasteners used for pressure-treated and fire-retardant-treated wood to be corrosion resistant and shall be compliant with Sections 2004.10.5.1 through 2304.10.5.4. Coating requirements for zinc coatings and stainless steel fasteners are specified in the IBC.	No NFIP requirement
Fasteners and connectors for preservative-treated wood (cont.)	**2018 IBC, 2304.10.5.1 Fasteners and connectors for preservative-treated wood.** Requires all fasteners used for pressure-treated wood to be corrosion resistant. Specific requirements for connectors are outlined in the IBC. The coating type and weights of connectors shall either be as specified by the manufacturer or meet the minimum requirements as specified in the IBC. An exception for carbon steel fasteners is outlined in the IBC. **2018 IBC, 2304.10.5.2 Fastenings for wood foundations.** Requires all fasteners used for wood foundations to be compliant with the American Wood Council's *Permanent Wood Foundation Design Specification with Commentary,* 2015 Edition (ANSI/AWC PWF-2015 [2014b]). **2018 IBC, 2304.10.5.3 Fasteners for fire-retardant-treated wood used in exterior applications or wet or damp locations.** Requires all fasteners used for fire-retardant-treated wood in exterior applications or wet or damp locations to be corrosion resistant. Specific requirements for fasteners are outlined in the IBC. **2018 IBC, 2304.10.5.4 Fasteners for fire-retardant-treated wood used in interior applications.** Requires all fasteners used for fire-retardant-treated wood in interior locations to be as specified by the manufacturer, or if those specifications do not exist, the fasteners meet the requirements of Section 2304.9.5.3. Changes from 2015 to 2018 IBC: Standards for driven fasteners and the need for staples to be stainless steel were added. Changes from 2012 to 2015 IBC: Section 2304.9.5 was renumbered to 2304.10.5.	No NFIP requirement
Flood damage-resistant materials	**ASCE 24-14, Section 5.1 General** Requires that, in flood hazard areas, all materials used in new construction and substantial improvaements be constructed of flood damage-resistant materials below the required elevations specified in Table 5-1 of ASCE 24-14. Also requires materials to be of sufficient strength, rigidity, and durability to adequately resist all flood-related and other loads or to be designed as breakaway or as otherwise permitted in the standard. Change from ASCE 24-05: Duplicative statement at the end of the section on the need for materials to have sufficient strength, rigidity, and durability to resist flood loads was removed.	Equivalent to NFIP 44 CFR § 60.3(a)(3) with more specificity on requirements for connectors and fasteners
Metal connectors and fasteners	**ASCE 24-14, Section 5.2.1 Metal Connectors and Fasteners** Requires that metal connectors and fasteners exposed to floodwater, precipitation, or wind-driven water meet specific standards as outlined in ASCE 24-14 for corrosion resistance. Change from ASCE 24-05: Updated references to materials standards. **ASCE 24-14, Section 5.2.2.1 Corrosive Environments** Requires structural steel exposed to saltwater, salt spray, or other corrosive materials be hot-dipped galvanized after fabrication and other secondary components to meet the requirements of Section 5.2.1. Change from ASCE 24-05: No change.	No NFIP requirement

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4- Importance of Selecting Proper Connectors and Fasteners for a Continuous Load Path

Buildings are exposed to numerous forces (loads), including those associated with wind events, floods, snow accumulation, and earthquakes. For a building to survive exposure to such forces, loads must be transferred through the building's structure to the soils that support the building along what are typically referred to as load paths. Load paths consist of structural elements (e.g., beams, columns, bearing walls) and the components that connect these elements. In light-frame construction, structural elements are often connected with metal connectors and fasteners (fasteners include screws, bolts, and nails). Examples are shown in Figure 1.

Metal connectors are premanufactured components that are usually cut from flat steel sheets and formed into a shape to efficiently transfer loads from one structural element to another. The load capacities of metal connectors, often determined by the manufacturer through testing or analysis, are published for use by design professionals and contractors to meet the load requirements for their project.

Metal connectors and fasteners are important elements in transferring loads from natural hazards (e.g., flood, wind, seismic) through a building. Corrosion rates for metal are dramatically higher in coastal environments than in less harsh, non-coastal environments. Therefore, it is important to increase the corrosion protection for metal connectors and fasteners in coastal environments. See Section 6 for information on the causes of corrosion in coastal areas. Studies have shown that stainless steel and thick hot dip galvanized (G185 or higher) metal connectors and fasteners improve corrosion protection. Selecting metal connectors and fasteners made of the same metal and either hot dip galvanized, or stainless steel will improve performance. See Section 8 for information on improving corrosion resistance.

Regardless of the metal that is selected, routine inspection is important to identify when replacement is necessary. See Section 9.2 for information on inspections.

Preservative-treated lumber, which is commonly used in many buildings, requires special attention when selecting connectors and fasteners. See Section 5.1.1.

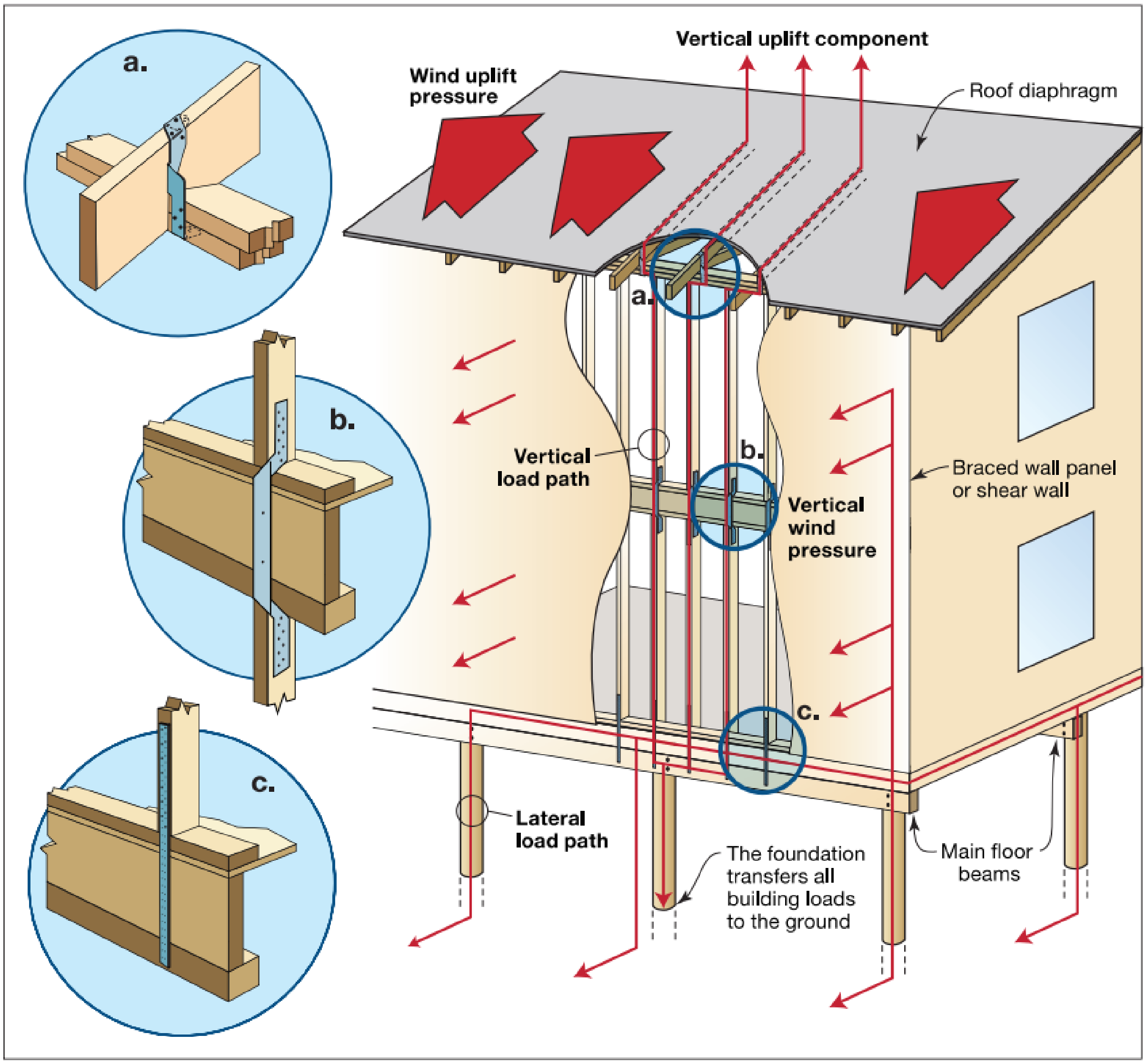


Figure 1: Example of using metal connectors and fasteners to create a continuous load path

5- Light Gauge Metal Connectors and Corrosion

The term "light gauge metal connectors" is used in this technical course to highlight the importance of corrosion protection for lighter gauge connectors such as the prefabricated connectors that are used to facilitate wood connections. However, metal connectors fabricated from thicker steel will also benefit from this guide.

Light gauge metal connectors are commonly used in several locations throughout wood-framed buildings. Concrete and masonry structures may also be used. Although light gauge metal connectors are not unique to wood-framed buildings, this technical course highlights aspects of using them in wood framed buildings in areas where corrosion can occur.

Light gauge metal connectors are often used to create a load path by securing roof framing to the tops of load-bearing walls, connecting walls of upper floors to lower floors, and connecting walls to foundations. The selection of the type of metal connector to use for specific applications may be dictated by the building code or may be based on the relative ease a type of connector offers in making complex framing connections. Metal connectors such as wind anchors may be used instead of toe-nailed connections to increase the strength of connections of a roof truss to a top plate (see Figure 2). In some cases, such as when attaching floor joists to floor band joists, metal connectors can both improve the connection and reduce labor costs (see Figure 3). In some portions of a building's load path, light gauge metal connectors can make the connection several times stronger than a connection that is readily achievable by nails alone.

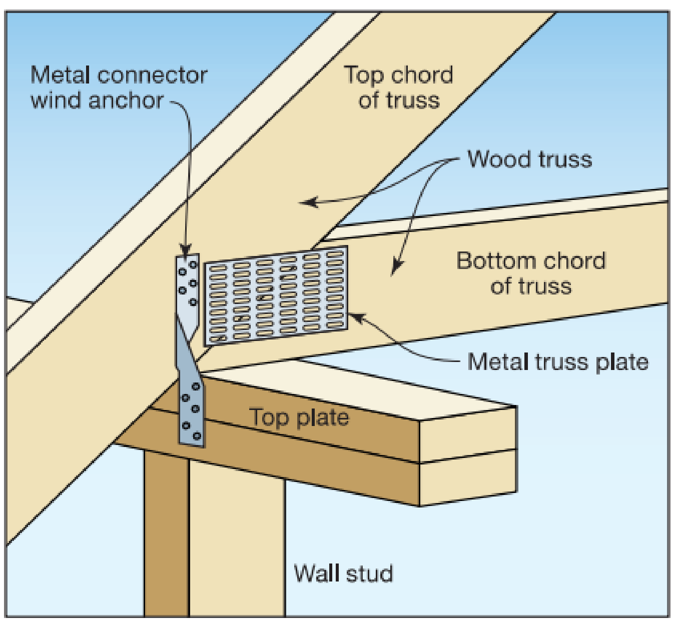


Figure 2: Common wind anchor and metal truss plate

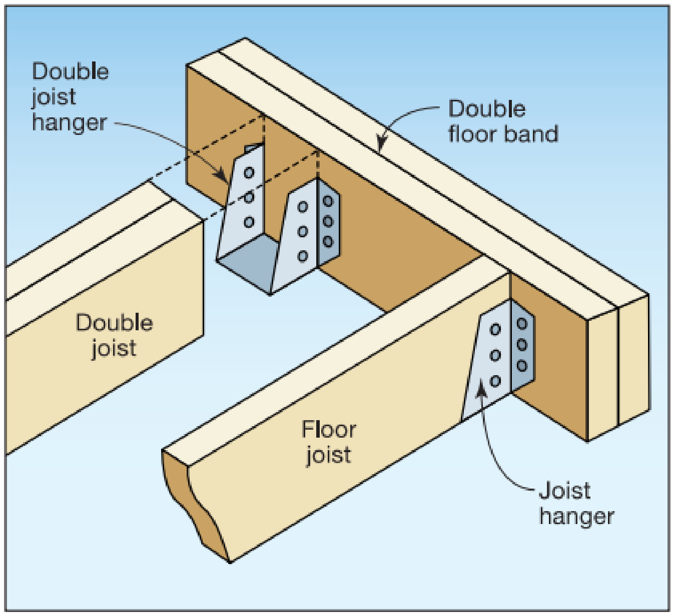


Figure 3: Common single- and double-joist hangers

Despite the benefit of being stronger than nails alone, light gauge metal connectors have drawbacks in coastal environments. Metal connectors that are prone to corrosion can lead to load path failures and structural damage during natural hazard events. The following are examples of important metal connectors potentially subject to corrosion:

- Hurricane straps and wind anchors used to connect roofs to walls (see Figure 2)
- Truss plates that connect the members of pre-manufactured roof and floor framing systems
- Joist hangers used on floor joists (see Figure 3), beams, and rafters
- Other metal connectors such as those used to improve lateral load resistance

5.1 Known Concerns Related to Nominally Galvanized Metal Connectors

In this technical course, the term "nominally galvanized metal connectors" refers to connectors that have the minimum galvanization provided by the manufacturer and that do not have corrosion resistance beyond the minimum. Nominally galvanized metal connectors should be upgraded when enhanced corrosion resistance or greater strength in the connection is needed or desired.

5.1.1 Chemicals in Preservative-Treated Wood

Salt spray in coastal environments and the chemicals in the preservatives that are used to treat wood can both contribute to the corrosion of metal fasteners. One of the chemicals in preservatives, chromated copper arsenate (CCA), was removed in 2004 from formulations for preservative-treated wood for most building applications. Several formulations to replace CCA were developed, including some that are more chemically reactive and therefore more corrosive to metal connectors and fasteners. As a result, manufacturers of several of the new formulations specified that all fasteners used with preservative-treated framing be stainless steel or hot-dip galvanized metal with a defined minimum amount of galvanizing.

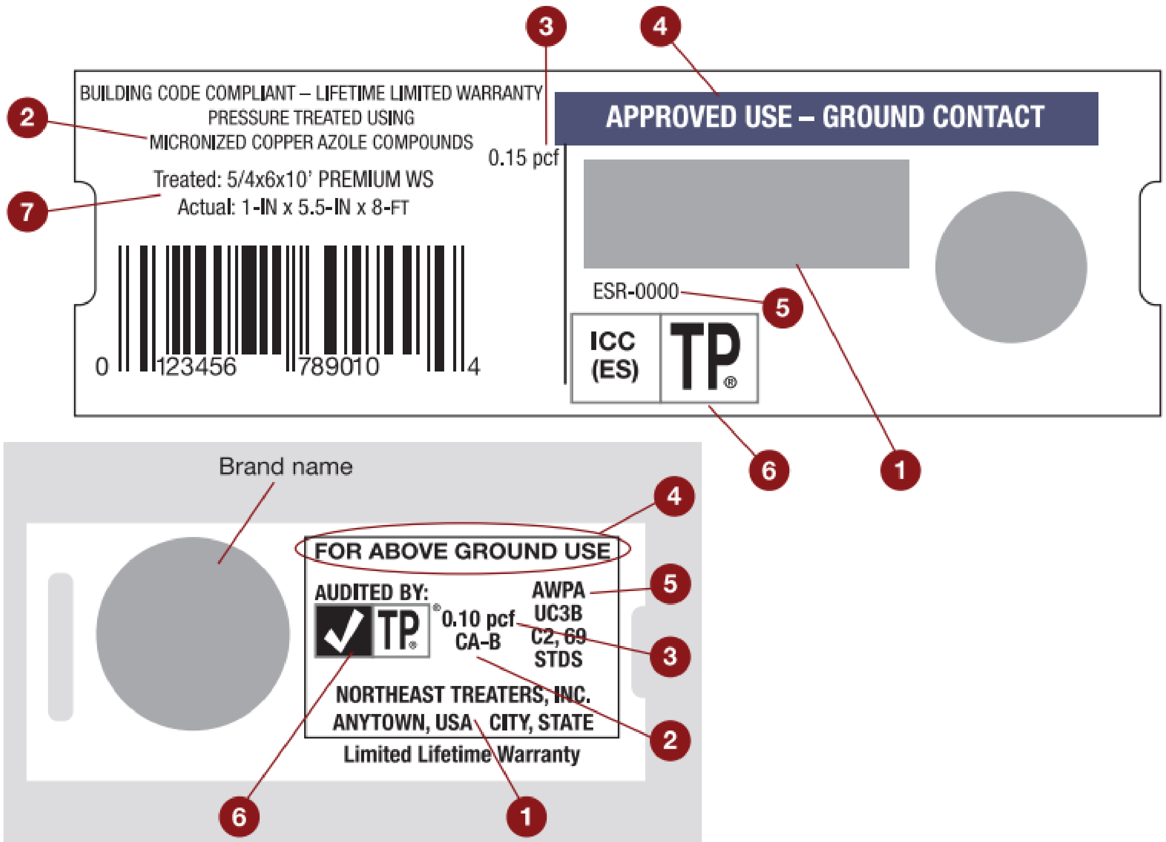
Which chemical is used in the treatment and the amount of chemical in the wood after treatment, referred to as retention, can both influence the corrosion rate. Wood treated for use in more severe environments, such as in direct contact with the ground, has higher chemical retention than wood treated for use in less severe environments. Higher retention can increase the corrosion rate. Connector manufacturers may have recommendations regarding selecting connectors and fasteners that will be in contact with treated wood.

Lumber manufacturers attach identification tags to treated wood products to indicate the type of preservative that was used (see Figure 4). The tags allow designers and builders to select connectors and fasteners that are compatible with the amount and type of preservative in the wood and its intended environment.

5.1.2 Galvanic Corrosion

Galvanic corrosion is the corrosion that results when two metals with different electrical potential are in contact with each other and are in the presence of an electrolyte such as saltwater. Galvanic corrosion is an electrochemical process in which one of the metals corrodes and the other one is protected.

Metals can be protected from galvanic corrosion by applying a sacrificial metal to a metal surface (see Section 8). The metals involved in galvanic corrosion can be (1) the metallic compounds in wood preservatives and the metal connectors the compounds are in contact with or (2) metal connectors and adjoining fasteners if they are made of dissimilar metals such as stainless steel and aluminum. *It is important that fasteners and connectors be made of similar metals to prevent galvanic corrosion.* Galvanic corrosion can occur anywhere but can occur more quickly in coastal environments.



Preservative-treated wood is commonly referred to as "pressure treated" lumber and has an identification tag attached to the lumber. The tag contains the following information:

1 Identification of treating manufacturer
2 Type of preservative
3 Minimum preservative retention (pcf)
4 End use for which the product is treated
5 Standard to which the product was treated or ICC-ES Evaluation Report Number
6 Identity of the approved inspection agency
7 Size, Length, Grade, Species (Optional)

Figure 4: Wood product identification tag

5.2 Metal Connector and Fastener Materials and Fabrication

Most light gauge metal connectors are made from thin, flat sheets of steel that have been galvanized (has a zinc coating that was applied during fabrication). In flat sheet form, steel is sufficiently strong for connectors and is readily workable and relatively inexpensive, all of which make it well suited for connectors. Most fasteners (e.g., screws, bolts, nails) are also made of steel.

Unprotected (ungalvanized) steel is subject to corrosion, even in inland areas, and corrodes rapidly in salt air. To protect against corrosion, most light gauge metal connectors and fasteners are galvanized.

CORROSION OF BRICK TIES

Metal brick ties and their fasteners are also subject to corrosion. Fact Sheet 5.4, "Attachment of Brick Veneer in High-Wind Regions" in FEMA P-499, *Home Builder's Guide to Coastal Construction* (2010a), contains recommendations on improving the attachment of brick veneers to buildings. The recommendations in this Technical Bulletin for corrosion-resistant connectors and fasteners also apply to the proper selection of corrosion-resistant brick ties and fasteners.

5.2.1 Galvanizing

Galvanizing is the process of coating steel with zinc.

In hot-dip galvanizing, the steel is carefully cleaned and then dipped into a vat of molten zinc. The high temperature melts the surface of the steel and forms several steel/zinc alloys that tightly bound the zinc coating to the steel base metal; various thicknesses of zinc coatings are achievable. The protective zinc coating still corrodes, but the corrosion of the zinc protects the steel base metal. Galvanized steel can degrade up to more than 50 times slower than ungalvanized steel in the same coastal environment.

Zinc can also be applied mechanically. The method typically involves tumbling the metal parts in acid and copper to mechanically weld a zinc coating onto a steel surface. This method is preferred for applying zinc to threaded parts, such as machine screws, because it creates a uniform thickness of the coating. As with hot-dip galvanizing, various thicknesses of zinc coatings are achievable.

Mechanically galvanized fasteners are appropriate for some applications, but mechanically applied galvanized coatings are typically thinner and more brittle than hot-dip galvanized coatings, so mechanically galvanized fasteners are discouraged for exterior applications, particularly in coastal environments. The IBC and IRC prohibit mechanical galvanizing for driven fasteners such as nails and timber rivets because mechanically galvanized coatings may deteriorate during installation. For these applications, hot-dip galvanized coated steel or stainless steel fasteners are recommended.

HOT-DIP GALVANIZING COATING DESIGNATION SYSTEM

ASTM A653 (2015a) uses a coating designation for hot-dip galvanizing that indicates the amount of galvanizing in ounces per square foot (oz/ft^2) of surface area. For example, hardware designated as G185 has a galvanized coating that weighs 1.85 oz/ft^2 (the weight includes both surfaces of the coated material) and a minimum of 0.64 oz/ft^2 on one side because coatings are not always evenly distributed on both sides. Metal connectors are often stamped with the coating designation, but fasteners generally are not, so it is necessary to look at the packaging to determine the amount of galvanizing for fasteners.

5.2.2 Protective Properties of Zinc

Galvanizing is particularly effective for steel because, unlike most other coatings, zinc sacrificially protects bare steel edges and scratches. The zinc surface near a scratch corrodes slightly faster than the zinc surrounding it and fills small scratches with zinc corrosion products, preventing the steel from rusting until the nearby zinc is consumed. The protection of bare edges and scratches offered by galvanizing is important because many connectors are fabricated after the steel sheet metal has been galvanized, and fabrication can remove the zinc and expose the base metal.

Zinc also differs from other coatings (or paints) and most metals by corroding at a relatively steady rate in most atmospheric exposures. Therefore, doubling the thickness of the zinc coating approximately doubles the protection period.

5.2.3 Standards and Codes

ASTM International (ASTM) has established national standards for galvanizing that are referenced by the I Codes, ASCE 24, and most local building codes. The standards are included in the following:

• Hot-dip galvanized steel sheets used in the manufacture of metal connectors are covered in ASTM A653, *Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process* (2015a).
• Metal connectors that are hot-dip galvanized after fabrication are covered in ASTM A153/A153M, *Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*

(2016).
• Hot-dip galvanizing of most fasteners is covered by ASTM A123, *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products* (2015b).
• Mechanically applied galvanizing is covered in ASTM B695-04, *Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel* (2004), which states that Class 55 is the minimum thickness allowed to be in contact with preservative-treated lumber.

The I-Codes require that treated wood or the connector manufacturer's recommendations be followed when connectors are in contact with preservative-treated lumber. In the absence of direction, the I-Codes require that a minimum G185 zinc-coated steel be used (some exceptions are provided). Use of Type 304 or Type 316 stainless steel is regarded as exceeding the minimum G185 zinc-coated steel code requirement for corrosion protection. Stainless steel types are explained in Section 8.2 of this Technical Bulletin.

5.2.4 Proprietary Coatings

For some types of fasteners, particularly screws, manufacturers use a proprietary coating rather than simple galvanization. One advantage of using proprietary coating is that the coating can be more uniform to allow the threads to function normally. Manufacturers may have a building code evaluation report to show that their coating is equivalent to one of the prescriptive corrosion-resistant coatings required by the codes.

6- Causes of Corrosion in Coastal Areas

Corrosion of metal fasteners and connectors is accelerated when a certain level of surface wetness is exceeded, initiating electrochemical reactions among the metal, salts, and air. The conditions that accelerate the rate of corrosion near the coast have been studied at a few field stations and in research laboratories. The studies identified the major factors that contribute to accelerated corrosion rates as including proximity to the shoreline, high temperature, high humidity, elevation, exposure class (see text box) including sheltering, and certain airborne pollutants. While it may be infeasible to determine the rate of corrosion at specific sites, it is helpful to understand the factors that contribute to corrosion so that appropriate design, construction, and maintenance activities can be implemented.

EXPOSURE CLASS

As used in this Technical Bulletin, the term "exposure class" relates to areas of buildings exposed to different conditions that affect corrosion. It is different from the term "Exposure Category," which is used in the wind load requirements of the I-Codes.

Exposure classes are outlined in Section 7 of this Technical Bulletin.

6.1 Salt Spray from Breaking Waves and Onshore Winds

Salt spray from breaking waves and onshore winds significantly accelerate the rate of corrosion of metal connectors and fasteners. Ocean salts, which are primarily sodium chloride but include other chlorides and compounds, accumulate on metal surfaces and accelerate the electrochemical reactions that cause rusting and other forms of corrosion. The combination of salt accumulation on the surface and the high humidity common in many coastal areas further accelerates the corrosion rate of untreated steel and other metals commonly used in connectors, fasteners, and other building materials. The longer the surface remains damp during the normal daily fluctuations in humidity, the higher the corrosion rate. Onshore winds carry both salt and moisture inland from the ocean. Therefore, corrosion rates are higher along shorelines with predominantly onshore winds than along shorelines with predominantly offshore winds.

6.2 Distance from Ocean

When waves break, salt water is aerosolized, and the wind tends to distribute the salt spray to inland areas. The amount of salt spray in the air is greatest near breaking waves and declines rapidly in the first 300 to 3,000 feet landward of the shoreline. Despite the inland reduction, studies have shown accelerated corrosion rates as far inland as 5 to 10 miles (IMOA, 2009). Farther landward, corrosion can be similar to the rates that occur in milder, inland conditions.

Although the width of high-corrosion areas varies along the shoreline, it is appropriate to assume that oceanfront and nearshore buildings can be more severely affected than buildings farther inland. Tests in North Carolina in the 1940s found that samples of iron corroded 10 times faster 80 feet landward of the shoreline than samples of the same material 800 feet landward of the shoreline (LaQue, 1975). Similar results have been noted around the world.

6.3 Elevation Above Ground

LaQue (1975) determined that elevation above the ground, in addition to distance from the ocean, affected rates of corrosion in tests at Kure Beach, NC. The tests showed that the rate of corrosion reached a peak at approximately 12 feet above the ground near the shoreline (see Figure 5), approximately equal to the lowest floor elevation of an elevated building with parking underneath. In several rows of buildings farther inland, the corrosion rate was found to be lower, but the rate was highest at an elevation above the roofs of small buildings. The tests also indicated that the highest corrosion rate near the ocean was more than twice the corrosion rate farther inland.

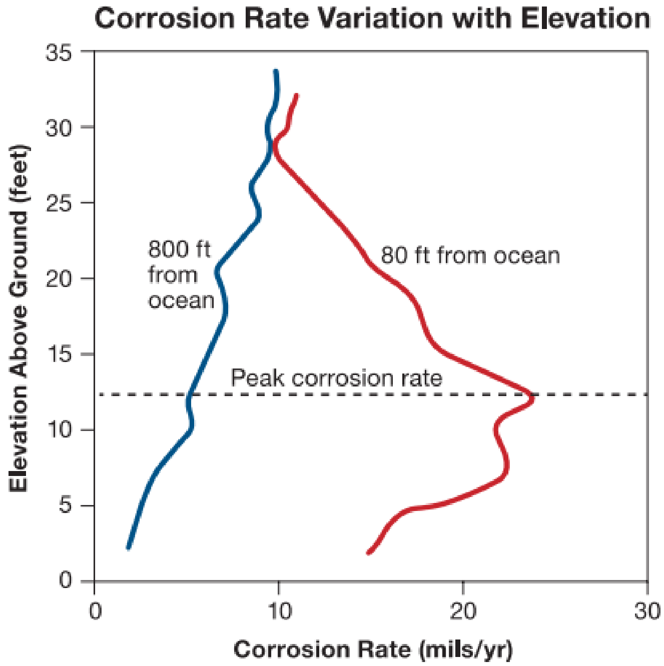


Figure 5: Variation in the corrosion rate of steel with elevation at two distances from the ocean for Kure Beach, NC (LaQue, 1975)

6.4 Exposure to Corrosion and Building Orientation

Both exposure and building orientation affect corrosion rates (exposure classes are described in Section 7 of this Technical Bulletin). Exposed areas such as building exteriors are often coated with large amounts of salt spray and can be expected to suffer high corrosion rates. LaQue (1975) found that the metals on the side of a building facing the ocean corrode much faster than those facing away from the ocean.

Perhaps less obvious is LaQue’s finding that partially sheltered exposures, such as areas under piling supported buildings or under decks and walkways, can experience even greater corrosion than open exposures. Tests showed that portions of buildings exposed to rain may undergo lower corrosion rates than sheltered areas because rain can periodically wash away salt accumulations. Sheltered or covered areas, on the other hand, do not benefit from occasional rinsing from rain and therefore accumulate more salt, resulting in higher corrosion rates.

Another effect of exposure and building orientation is related to the duration of surface wetness. Open exposures dry more readily because they are exposed to sunlight, and rapid drying slows the corrosion rate. Partially sheltered exposures stay damp longer and therefore may corrode faster.

6.5 Weather and Rates of Corrosion

Weather affects the rate of corrosion of metal in both coastal and inland locations. Most chemical reactions, including corrosion, are affected by temperature, humidity, wind speed, and other factors. Higher temperatures and higher humidity increase corrosion rates. Like any weather-driven condition, corrosion rates can vary considerably from year to year.

Short-term measurements of corrosion rates at specific locations can be misleading unless compared to long-term averages for nearby locations because average weather conditions for factors such as rainfall seldom occur. In any given year, measured rainfall can be much higher or lower than the average rainfall.

As a result, the corrosion rate for a given area in an individual year may be significantly higher or lower than the long-term average rate. Because corrosion rates vary, inspections and maintenance should be done at least annually, and preferably more often, to identify connectors and fasteners that need to be replaced. See Section 9.2 for more information on maintenance and replacement.

6.6 Identifying Areas with Increased Corrosion Rates

Corrosion tests can help define the coastal areas where corrosion is most severe, and extra precautions should be taken to minimize corrosion of metal connectors and fasteners. Unfortunately, corrosion data is not available for most coastal communities, and building professionals must rely on local experience to estimate the areas where corrosion-resistant materials and methods are needed.

Areas of increased corrosion concern can be identified by observing the state of corrosion of metal connectors and fasteners in older buildings located at various distances from the shoreline. The observations can be documented and used to delineate areas with higher corrosion rates. Alternatively, communities or builders can conduct field tests using a test kit or laboratory to determine areas where increased corrosion protection should be used.

7- Exposure Classes for Connectors and Fasteners

Corrosion exposure types for metal connectors and fasteners in most buildings can be grouped into five classes, which are discussed in this section. The five classes and their locations in a building are shown in Figure 6.

Exposure classes should be considered when determining which connectors and fasteners are appropriate for a given application. The use of corrosion-resistant fasteners and connectors, such as those that are made of stainless steel or incorporate thicker zinc galvanizing (G185 or thicker), will reduce corrosion rates or extend the period that the zinc coating protects the base metal. Using corrosion-resistant fasteners and connectors will maintain the designed load path longer than nominally galvanized connectors and fasteners. In areas where corrosion is the most problematic, the most corrosion-resistant metal connectors and fasteners, such as Type 304 or Type 316 stainless steel, should be used.

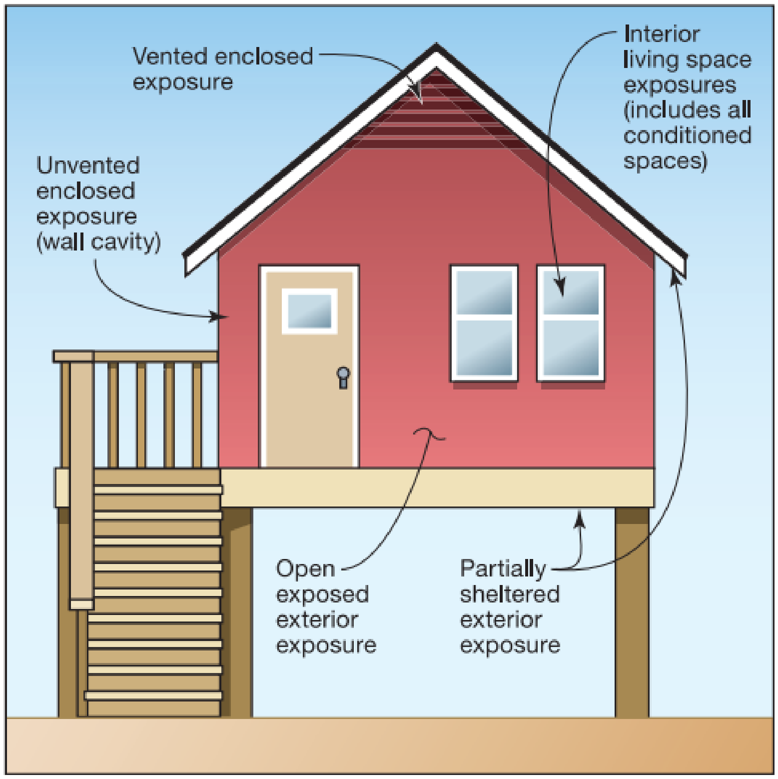


Figure 6: Corrosion exposure classes and their locations

> **SELECTING FASTENERS AND CONNECTORS**
>
> Before selecting fasteners and connectors, consult the locally applicable code and relevant design standards for requirements to determine the minimum level of corrosion protection necessary.

7.1 Partially Sheltered Exterior Exposure

Examples of *partially sheltered exterior exposures* are open, under-house storage; parking areas below a piling-,column-, or post-supported buildings; and areas under roof overhangs, decks, screened-in porches, and walkways.

In partially sheltered areas, corrosion can significantly weaken nominally galvanized light gauge metal connectors in 5 to 10 years or sooner. When not concealed by exterior finishes, these areas can often be inspected to evaluate the condition of the connectors and determine when maintenance or replacement is necessary.

7.2 Open Exposed Exterior Exposure

Open exposed exterior exposures are areas such as exterior walls where metal connectors and fasteners are exposed to the elements.

If metal connectors and fasteners are exposed to rainwater and usually dry fully between wettings from ocean spray, as can occur in open exposed exterior exposures, the corrosion rates will likely be lower than in partially sheltered exterior exposures. However, if fasteners and connectors in open exposed exterior exposures do not benefit from rainwater washes or remain wet for extended periods, the corrosion rates in these exposures can match the rates in partially sheltered exterior exposures.

Connectors in open exposed exterior exposures can usually be inspected to evaluate their condition, and if access is sufficient to remove the fasteners, connectors can often be replaced if found to be weakened by corrosion.

REGULAR INSPECTION AND MAINTENANCE

Owners may not be aware that maintenance is necessary for connectors and fasteners and may not be able to inspect some areas where corrosion can occur. Owners should be advised to regularly inspect connections and that replacement of metal connectors and fasteners may be necessary to maintain the structural integrity of their buildings. In areas where inspections or replacements are difficult and corrosion is possible, designers and builders should use materials with higher degrees of corrosion resistance, such as stainless steel.

7.3 Vented Enclosed Exposures

Examples of *vented enclosed exposures* are attics, which must be vented to release excess heat and moisture, and rafter and floor cavities if vents are installed.

Corrosion of metal connectors and fasteners in vented enclosed exposures depends on the location of the metal connectors in the enclosed space. Corrosion rates near vents, where outside airflow is concentrated, are often similar to the rates in partially sheltered exterior exposures (see Section 7.1). Corrosion rates for metal connectors that are not near vents or that are covered by insulation are expected to be much lower.

Some vented enclosed areas can be hard to access, complicating inspections to evaluate the condition of the metal connectors and replace them when needed. In these locations, it is worth considering a more corrosion-resistant metal connector since its condition will rarely be evaluated.

7.4 Unvented Enclosed Exposures

Examples of *unvented enclosed exposures* are enclosed areas such as wall cavities, enclosures surrounded by breakaway walls under elevated buildings, and floor framing cavities created when finishes are installed on the underside of floor joists.

Because of the limited airflow and incoming salt spray, corrosion rates for connectors in these exposures are expected to be lower than the rates in partially sheltered exterior exposures, open exposed exterior exposures, or vented enclosed exposures. However, since many connectors and fasteners installed in unvented enclosed exposures are concealed by finishes and would require removing building materials to gain access to the fasteners, inspection to evaluate their condition is generally impractical. Therefore, installing corrosion-resistant (or more corrosion-resistant) fasteners and metal connectors in these areas should be considered responsible construction practice.

7.5 Interior Living Space Exposures

Interior living space exposures are the areas within a building that are usually heated or air conditioned.

These spaces are sealed from most salt spray, and the humidity control provided in most conditioned spaces generally reduces humidity levels below those that contribute to accelerated corrosion rates.

In coastal areas, using more corrosion-resistant fasteners such as mechanically galvanized fasteners will better protect connections in the interior portions of exterior walls and wall connections to attic spaces as long as they do not receive salt spray. These areas typically have a relatively low chance of corrosion and are free of preservative-treated lumber. Fasteners for interior walls can be uncoated or electroplated galvanized fasteners.

8- Improving Corrosion-Resistant Materials and Coatings

The durability of metal connectors can be improved by using more corrosion-resistant materials such as Type 304 or Type 316 stainless steel or by treating metal connectors after fabrication with hot-dip or mechanical galvanizing. Improving corrosion resistance is discussed in this section.

Materials with improved corrosion resistance may cost more initially, but reduced maintenance over the life of a building can partially or completely offset the cost.

Another important consideration in selecting connectors and fasteners is the accessibility of the connections. Fasteners and metal connectors located in areas that cannot be readily inspected or where the fasteners and metal connectors cannot be easily replaced should be made of materials with higher corrosion resistance. Since corrosion not only reduces the strength of a connection, but more importantly, can result in a load path failure, it is important to use durable connectors in building areas that are difficult to access.

Metals may be selected because of their strength, temperature resistance, durability, availability, cost, and other reasons. As mentioned in Section 5.1.2, dissimilar metals can undergo a process called galvanic corrosion if they come into contact with an electrolyte such as saltwater. When in contact with an electrolyte, charged particles flow between the dissimilar metals, which causes one of them to corrode and the other to be protected. Which metal corrodes and which one is protected depends on the relative affinity to attract or repel electrical changes. The reactivity, the rate of corrosion that occurs, which metal will corrode, and which one will be protected can be evaluated using a galvanic corrosion chart such as the one shown in Figure 7.

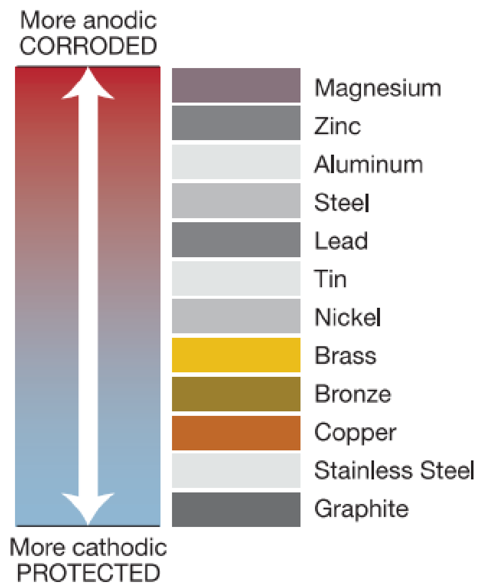


Figure 7: Galvanic chart of common metals

The chart shown in Figure 7 is simplified, but it shows individual metals' relative affinity for attracting or repelling electrical charges. Metals closer to the top of the chart tend to function as anodes and undergo galvanic corrosion. Metals closer to the bottom tend to function as cathodes and are protected. Metals function as anodes or cathodes depending on the metal they are paired with. For example, nickel will function as a cathode and be protected when in contact with zinc or aluminum but will function as an anode and corrode when in contact with copper. Metals not affected by galvanic corrosion can still corrode through exposure to compounds like salt.

In addition to depicting which metals will function as anodes and cathodes, a galvanic chart can also depict the relative rate of corrosion that two metals may experience. Metals that are relatively close to each other on the chart will have low rates of corrosion, while those that are more widely separated will corrode more quickly. For example, when exposed to copper, bronze, which is relatively close to copper on the galvanic chart, will have a lower corrosion rate than steel, which is more widely separated from copper on the chart.

The strength of the electrolyte also comes into play. For any two dissimilar metals, the anodic metal will corrode more rapidly in an electrolyte that easily conducts electrical charges compared to a weaker electrolyte that does not easily conduct charges. Because of this, dissimilar metals in dryer environments, which tend to retard the flow of electrical charges, have lower corrosion rates than the same metals in areas with high moisture levels.

As shown by its location near the “Protected” end of the chart, stainless steel is more resistant to galvanic corrosion than most metals and is therefore the preferred metal in harsh environments and in areas where connector replacement will be difficult.

The galvanizing zinc protects steel in two ways: it acts as a physical barrier, and it slows the corrosion process because the zinc layer corrodes first, even protecting adjacent scratches in the coating. It should be noted that if a galvanized fastener is used in conjunction with steel plates, the galvanizing on the fastener will corrode much faster than when used in conjunction with galvanized plates.

8.1 Thicker Galvanizing

The galvanizing process does not eliminate the need for maintenance, but proper material selection can prolong the lifespan of the material and increase the potential for the fastener or metal connector to maintain its design strength. Increasing the thickness of the galvanized coating extends the length of time before the zinc corrodes to the point where the steel base metal begins to corrode.

The two methods of producing thicker galvanized coating on connectors are:

- Fabricating connectors from steel sheet with thicker initial galvanized coating
- Galvanizing connectors after fabrication

Galvanized sheet steel is available in a variety of coating thicknesses. Several manufacturers now market common connectors in various designs fabricated with G185 to G200 grades of galvanized protection, which, compared to standard G60 or G90 grades, have zinc coatings that are two to three times thicker. Since the corrosion resistance of zinc is proportional to the thickness of the zinc, G185 to G200 connectors should last approximately two to three times longer than G60 or G90 connectors.

Thicker galvanized coatings can also be attained by using the hot-dip process after connector fabrication. Several variables can affect the thickness of hot-dip galvanizing, but the result is typically a coating of zinc similar to the coating on a G185 connector. A few types of connectors with thicker galvanized coatings are regularly available. Other connector designs are available by special order.

Figure 8 illustrates that increasing the thickness of galvanizing results in a longer service life. The extent to which service life is increased depends on the location and the amount of salt in the air, as well as pollutants such as sulfur dioxide.

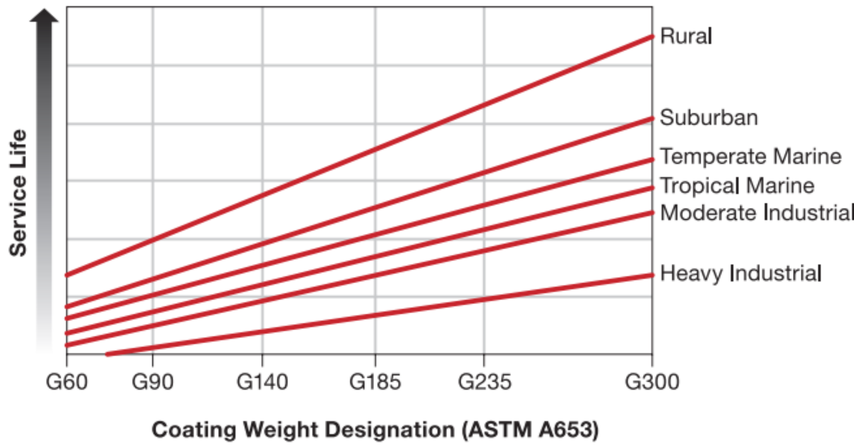


Figure 8: Approximate service life improvement from increasing galvanization thickness

Applying an additional outer coating in the factory or painting light gauge metal connectors fabricated from galvanized steel can enhance corrosion protection (see Section 8.3), and manufacturers can provide data on appropriate applications and compatible fasteners. However, paint should be used with caution because if it is scratched, it does not provide any corrosion resistance at that location.

8.2 Stainless Steel

Stainless steel is created when other metals are added to steel to make an alloy. The composition of the alloy determines its corrosion resistance, temperature resistance, and hardness and denotes the stainless steel type. Not all types of stainless steel have the same corrosion resistance, and some types are preferred over others in saltwater applications. Several connector manufacturers produce the most commonly used connectors in a stainless steel option. Stainless steel is resistant to corrosion in salt air, and it usually lasts longer than most other materials, even in the most corrosive oceanfront situations.

To eliminate the potential for galvanic corrosion, stainless steel connectors must be attached with stainless steel nails when separate fasteners are needed; otherwise, corrosion will be accelerated on the less corrosion-resistant metal and can dramatically reduce its lifespan (see Figure 7). In coastal applications, stainless steel should be Type 304 or Type 316. Type 316 is more resistant to corrosion and should be used for stainless steel metal connectors. Some fasteners are fabricated from Type 410 stainless steel, which has more corrosion resistance than galvanized bare steel but less than Type 316 stainless steel.

Stainless steel is tougher than normal carbon steel, which means that stainless steel connectors are more difficult to fabricate. Also, stainless steel tends to be more expensive than carbon steel and galvanized steel. When considering upgrading from galvanized fasteners and connectors to stainless steel, designers, contractors, and building owners in coastal areas should compare the cost of stainless steel connectors to G185 galvanized connectors, not to G60 and G90 galvanized connectors, which are not recommended in coastal areas. Furthermore, the reduced maintenance/replacement/labor life-cycle costs when using stainless steel should be considered when specifying connectors. See Section 9.2.2 for further details.

8.3 Applied Coatings and Paint

Coatings and paint applied to galvanized steel connectors can improve corrosion resistance, but many coatings and paints commonly used for buildings do not adhere well to galvanized surfaces. The Truss Plate Institute (TPI) has evaluated the use of truss plates in corrosive environments. If specified by the registered design professional or building designer, ANSI/TPI 1-2014 design specifications, which are referenced in the I-Codes, recommend that one of two industrial paint systems be applied by brush to embedded plates after delivery of the completed truss to the job site or after truss installation (ANSI/TPI, 2014). Alternatively, using truss plates with a thicker hot-dip galvanized coating is also recommended. The three industrial coating options for increasing corrosion resistance are:

- Epoxy-polyamide primer (SSPC-Paint 22)
- Coal tar epoxy-polyamide black or dark red paint (SSPC-Paint 16)
- Post-plate manufacture hot-dip galvanizing (zinc-based) per ASTM A153/A153M (ASTM, 2016)

The degree of improvement in corrosion resistance that the recommended applied coatings provide is difficult to estimate. Unlike differences in galvanized coating thickness, differences in paint system coating thickness do not proportionally change the corrosion resistance of the connector. Coating lifetimes are significantly affected by salt spray, but exposure conditions can affect coatings and galvanizing differently. Surface preparation and care in application are critical for improving corrosion resistance with coatings. The added cost of these coatings varies with local labor costs.

In general, other types of coatings and paints should not be assumed to significantly improve the corrosion resistance of nominally galvanized connectors and truss plates. For other types of connectors, the alternatives described previously are recommended over any other type of painting. However, for maintenance, zinc-based coatings may offer some benefits over standard coatings because zinc-based coatings can increase protection somewhat in areas where the coating is damaged. Stainless steel metal connectors should not be painted because the coating can prevent the protective oxide film that forms on the surface of stainless steel from developing. This oxide film is how stainless steel resists corrosion.

8.4 Other Corrosion-Resistant Fasteners

Manufacturers supply some fasteners with coatings other than galvanization and should be evaluated to ensure their corrosion resistance. ICC Evaluation Service (ICCES) produces acceptance criteria that manufacturers use to demonstrate that product performance is consistent with I Code requirements. ICC-ES published AC257, *Acceptance Criteria for Corrosion-Resistant Fasteners and Evaluation of Corrosion Effects of Wood Treatment Chemicals* (ICC ES, 2015), which provides criteria for alternative fasteners. The criteria outline requirements for testing fasteners in preservative-treated lumber in various types of accelerated corrosion environments. There are also evaluation reports regarding this acceptance criterion that provide information so that fasteners that are not galvanized or stainless steel can be considered for applicability in coastal environments. Without an evaluation report, manufacturers can often provide some information to allow comparisons with other more common methods of fabricating corrosion resistant fasteners.

ADDITIONAL INFORMATION ON CONNECTORS

Additional information on properly making connections between the foundation and the building can be found in FEMA's Hurricane Sandy Recovery Advisory RA1, *Improving Connections in Elevated Coastal Residential Buildings* (2013). The recovery advisory also discusses corrosion protection and lists resources for strengthening connections in wood-framed buildings.

9- Guidance for Connector and Fastener Corrosion Control

In corrosive environments, most construction materials deteriorate with time and eventually need to be repaired or replaced. In the United States, the service life of a wood-frame building could be approximately 70 years or more. With continued maintenance and periodic upgrades, buildings can remain serviceable well beyond that time. However, lack of maintenance and repairs can cause buildings to deteriorate much sooner than the average service life. Buildings located in coastal environments where steel components can corrode at a high rate are particularly susceptible to deterioration if not maintained regularly. Continued use of a building over its service life requires that:

• The original materials are durable enough to last the expected lifetime
• Periodic maintenance is conducted to extend the life of original materials
• Materials that have deteriorated are replaced

9.1 Reducing Corrosion Rates

Standard connectors are intended for inland use, and under normal conditions, they last as long or longer than other materials in a building. Although components of some buildings in coastal communities may have only slightly increased corrosion rates, buildings close to the ocean are likely to have drastically higher corrosion rates. In nearshore areas, the use of more corrosion-resistant materials and coatings is recommended in *partially sheltered exterior exposures, open exposed exterior exposures, vented enclosed exposures,* and *unvented enclosed exposures* (see Figure 6). Use of nominally galvanized metal connectors should be limited to interior areas that can be protected from corrosion (interior living space exposures).

Additional considerations in reducing corrosion rates are as follows:

• Consider changing the exposure class where connectors are used. For some uses, corrosion rates can be reduced by altering the exposure of the connectors. For example:

– Connectors typically found on building exteriors should be fully covered if possible or otherwise protected from salt spray and moisture. Applying exterior siding to fully cover the connections is one way to change the exposure from *open exposed exterior exposure* to an *unvented enclosed exposure condition.*

– An easy way to protect joist hangers and truss plates in the floors of piling-supported buildings is to sheath the underside of the floor joists to reduce the exposure to salt air. Adding such sheathing transforms one of the worst exposures, *partially sheltered exterior exposure,* into the less corrosive *unvented enclosed exposure condition.* However, when corrosion occurs, it can go undetected, so screws or some other removable fastening mechanism should be used to allow periodic inspection.

• Consider using alternate materials or connection methods. For some connections, such as floor joistto-floor beam connections, corrosion may be minimized by not using light gauge metal connectors, especially in *partially sheltered exterior exposures* and *open exposed exterior* *exposures.* Construction practices that were commonplace before the advent of light gauge metal connectors can be used to connect wood framing. With many practices, metal fasteners (nails, wood screws, lag screws, and bolts) are used with wood framing, and the metal fasteners are nearly fully concealed and protected from the elements by wood components. In many connections, only the head of the fasteners remain exposed to salt spray. When used with preservative-treated lumber, stainless steel nails and other corrosion-resistant fasteners should be used. See Section 9.2 for more guidance on maintenance and replacement. See the applicable building code for information on when these alternate methods are permitted and the size and number of fasteners that are required.

Figure 9 and Figure 10 show common methods of connecting wood framing members with only nails, screws, lag screws, and bolts. In both methods, the shafts of the fasteners are not exposed to salt spray.

The drawback of these methods is that their capacity to resist loads is not readily known since their strength depends greatly on fastener sizes and even more on the species of wood used. The design of wood framing connections is complex, and prescriptive methods are somewhat limited. The IRC and the *Wood Frame Construction Manual* (AWC, 2015) both contain nailing schedules, but neither contain prescriptive methods for connections such as those shown in Figure 10 and Figure 11. In contrast, the capacities of light gauge metal connectors are published by the manufacturers and verified by third-party testing. See the textbox below for more information.

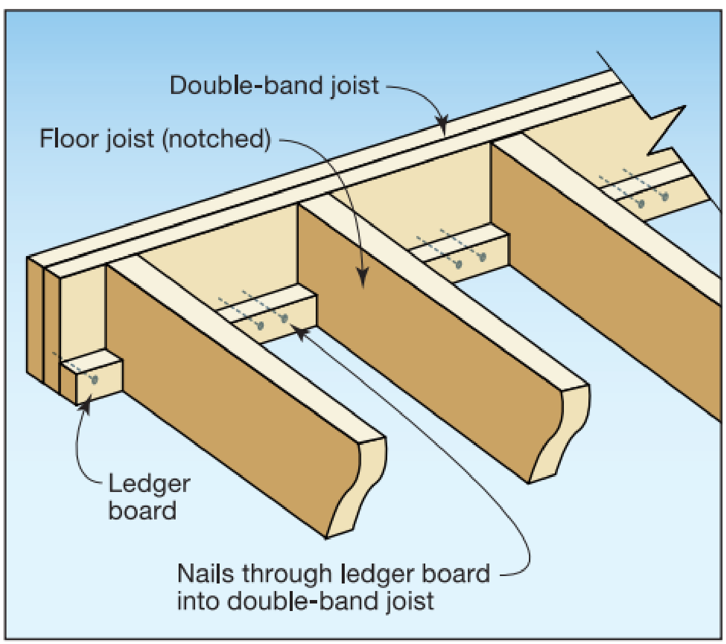


Figure 9: Traditional wooden ledger boards used in place of joist hangers in high corrosion areas

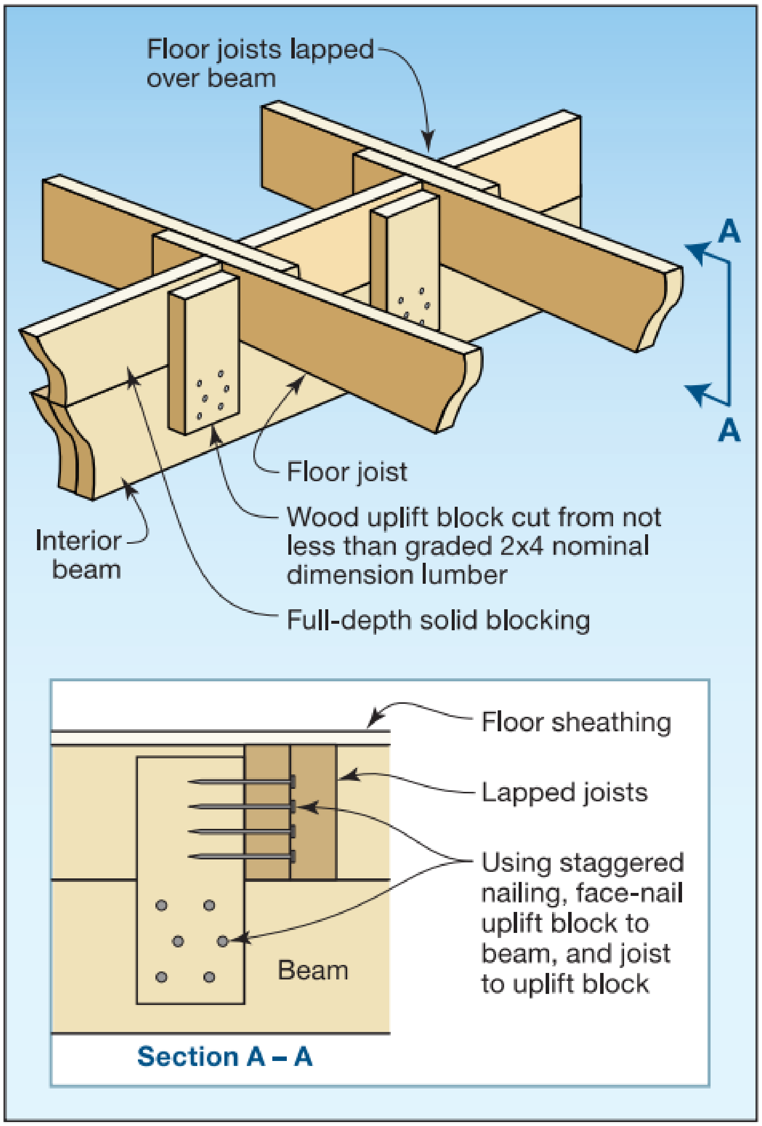


Figure 10: Detail of an elevated floor-to-beam connection using wood uplift blocking and full-depth solid blocking

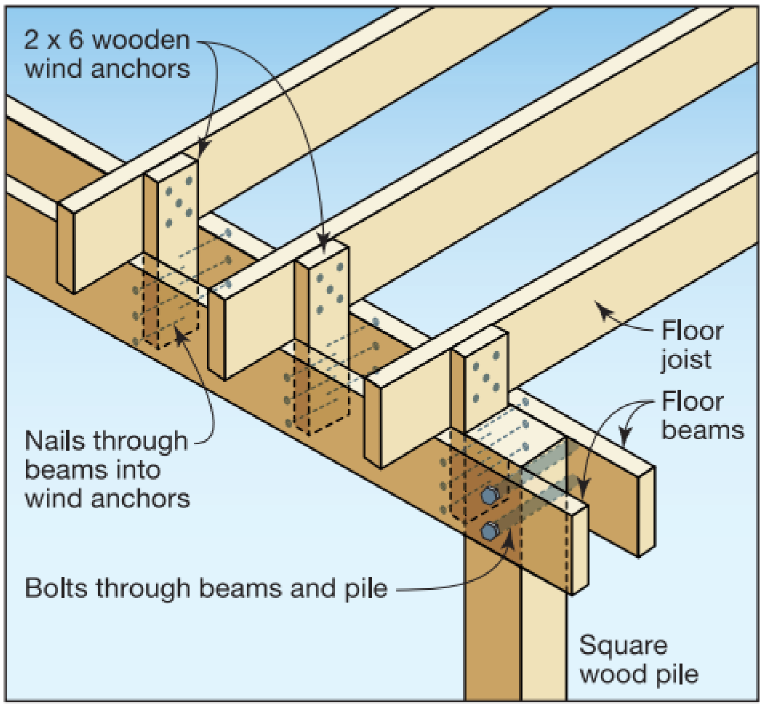


Figure 11: Wooden wind anchors used to connect floor joists to floor beams

STRENGTHS OF NAILED, SCREWED, LAGGED, AND BOLTED CONNECTIONS

The strength of connections made with dowel-type fasteners (nails, screws, lag screws, bolts, split ring connectors, shear plate connections, and timber rivets) is specified by ANSI/AWC NDS-15, *National Design Specification for Wood Construction* (2014a).

Allowable loads are determined by multiplying reference design values by all applicable adjustment factors. The reference design values are tabulated in NDS-15, Chapter 12; adjustment factors are contained in Chapters 11 and 12. Most adjustment factors are less than 1.0 (they lower the reference design values); several adjustment factors that account for load duration are greater than 1.0.

Reference design withdrawal values (W) for lag screws, wood screws, nails, and ring shank nails are listed in NDS-15, Tables 12.2A through 12.2D. Adjusted withdrawal values (W') are determined by applying all adjustment factors to those reference withdrawal values. Reference design withdrawal values and adjusted withdrawal values are measured per inch of fastener penetration or the depth of thread penetration for threaded fasteners.

Reference design lateral values (Z) for bolts, lag screws, wood screws, nails, and ring shank nails are tabulated in NDS, Tables 12A through 12T. Like withdrawal values, adjusted lateral design values (Z') are obtained by multiplying reference values by all adjustment factors.

The design values in the NDS are only for fasteners meeting the generic specification for that particular type of fastener. Fastener manufacturers have recently begun developing improved proprietary fasteners with higher design values. These design values can typically be found in the fastener's evaluation report.

9.2 Maintenance and Replacement Considerations

Inspection of fasteners and metal connectors is important and should be a regular maintenance activity undertaken by owners of buildings located in nearshore coastal environments. *Since many homeowners may not be aware of the effects of corrosion on the fasteners in their homes, communities in coastal areas should consider communicating to their citizens the importance of routine inspection and maintenance of connectors and fasteners.*

In some applications, connectors may be located where they are accessible and easily maintained. In areas where corrosion is less aggressive, such as locations farther from the coast, applying a coat of exterior house paint to exposed connectors may be enough to extend the life of the connectors. In areas with more aggressive corrosion, even annual painting is unlikely to prolong the life of connectors. In these areas, accessible connectors should be inspected for corrosion and replaced when necessary. Galvanized light gauge metal connectors should be replaced as soon as corrosion extends into the base metal (see Figure 12). The presence of more than thin rusty edges indicates that the zinc coating has been consumed, and the sacrificial effects have been lost. Corrosion of the thin, steel sheet will occur quickly and rapidly affect the structural integrity of the connector.

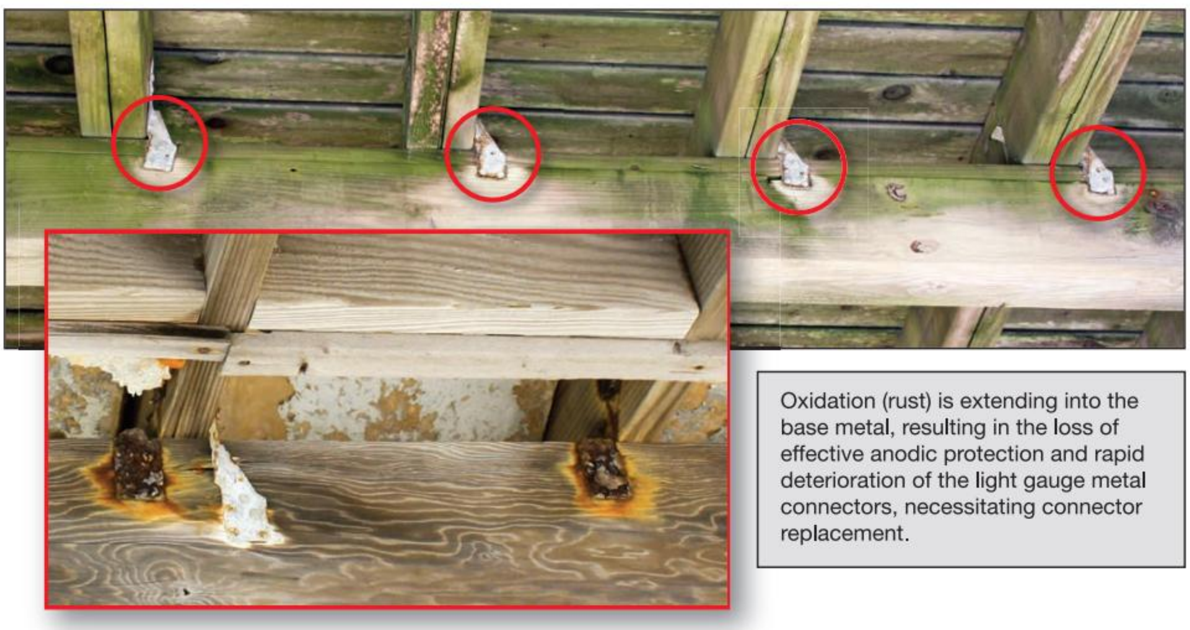


Figure 12: Zinc galvanizing on connectors that has corroded

9.2.1 Replacing Corroded Connectors

Replacement is the only option in existing buildings where connectors have already been damaged by corrosion. It is recommended that replacement connectors have different sizes or shapes or be fastened in different locations so that connections are too undisturbed wood. Since the availability of locations to attach replacement connectors into undisturbed wood may be limited, it is imperative that the most corrosion-resistant connectors and fasteners possibly be used to minimize replacements over the life of the structure. Inspections may also indicate a need to install connectors where they were not previously installed. For example, adding roof uplift connectors (hurricane clips) can significantly improve wind resistance and is generally worthwhile, even if some dismantling is needed to gain access. Wind retrofits are described for various levels of wind performance improvement in FEMA P-804, *Wind Retrofit Guide for Residential Buildings* (2010c).

9.2.2 Reducing Connection Maintenance for New and Existing Buildings

When evaluating the option of whether to initially install more corrosion-resistant metal connectors or replace them more frequently, the cost over the life of the building should be considered. Enhanced corrosion-resistant metal connectors, available for a moderately higher price, can have significantly longer lifetimes than nominally galvanized connectors. The cost of labor for initial installation is often the same for either option. The material and labor cost for even one replacement is typically many times more than the added cost of initially installing more corrosion-resistant materials. Using more corrosion-resistant materials during construction can avoid or reduce the cost of future repairs.

In areas where conditions foster aggressive corrosion and nominally galvanized connectors may have to be replaced as often as every 5 years, using more expensive materials such as stainless steel connectors and fasteners will likely prove less costly over the long run. Repeated replacement of metal connectors can be difficult since previously used fastener holes should not be reused. Different styles of metal connectors may provide different and faster locations to facilitate replacement but eventually damage from fastener holes may result in the need for more extensive repairs such as replacing structural members to maintain a continuous load path. Replacing structural members would be more expensive than upgrading to a more corrosion-resistant metal connector that would reduce the number of necessary connector replacements over the life of the building.

Given the difficulty of inspecting many connections after construction and the impossibility of inspecting others without invasive actions, using nominally galvanized fasteners and metal connectors in corrosive areas is fraught with potential problems and higher maintenance costs. There is a low likelihood that effective regular inspections to identify deterioration before the structural integrity is compromised would or could be performed. Even when problems with more vulnerable connectors can be identified, replacing damaged connections in existing buildings is usually costly and difficult. Furthermore, many connectors are hidden structural components that will go unseen and are difficult or impossible to maintain or replace. In such cases, replacement is rarely an option, and more corrosion-resistant materials should be selected during initial construction.

10- Summary of Best Practices for Corrosion Resistance

For many connector applications in corrosion-prone buildings, using materials with enhanced corrosion resistance is the best solution for new construction, and is also recommended for replacement connectors during maintenance or repair/renovation of existing construction. The choice of alternative connector material or coating specification should be guided by the following criteria:

• Location of the building relative to the observed corrosion hazards (primarily distance from the coast), as noted in Section 6
• Where the connectors will be used, as noted in Section 7
• Importance of the connection to the structure's load path, as noted in Section 4
• Life-cycle cost-effectiveness of the connector for the structure's service life, as noted in Section 9
• Long-term viability of the structure based on its potential service life and the need to maintain a proper load path throughout the life of the structure

Recommended materials for typical residential buildings are listed in Table 3.

In Table 3, building locations are identified as oceanfront buildings, intermediate rows of buildings in corrosion-prone areas, and buildings near the coast but far enough away from the ocean that excessive corrosion is not anticipated or has not been observed. Metal connectors with minimal galvanizing on oceanfront buildings are expected to corrode at high rates. In most communities, as buildings are constructed farther from the oceanfront, the rate at which corrosion occurs should decrease significantly at distances of 300 to 3,000 feet landward of the ocean. FEMA's Mitigation Assessment Team deployed to Puerto Rico following Hurricanes Irma and Maria and identified areas farther inland than 3,000 feet landward of the ocean where significant corrosion was noted on exposed structural connection that would be more consistent with the corrosion experienced by buildings closer to the shoreline (FEMA, 2018b). This finding suggests that in some areas, building owners may want to consider using hot-dip galvanized or stainless steel connectors farther inland than the 3,000 feet landward of the ocean guideline.

A site survey of surrounding buildings and structures may provide information on the severity of corrosion in specific areas, which will affect the useful life of connectors and fasteners. Another key factor for material selection is the exposure class of the connectors and fasteners; exposure classes are listed in Table 3 in order of decreasing severity of corrosion at particular locations. Since access to inspect or replace connectors and fasteners is a key consideration in whether to use more corrosion-resistant materials, an assessment of the severity of corrosion in the area and exposure class may provide additional insight into whether to use upgraded fasteners and connectors.

Table 3 also includes notes on truss plate treatments based on TPI recommendations for corrosive environments. Some of the recommendations in Table 3 are based on limited research. When the severity of the exposure is unknown, selecting more corrosion-resistant materials is prudent. In most cases, a Type 304 or Type 316 stainless steel connection or fastener will provide superior corrosion resistance, as shown in the galvanic corrosion chart in Figure 7.

Table 3: Recommendations on Corrosion-Resistant Materials and Methods

Exposure Class(1)	Accessibility(2)	Oceanfront, Second Row, and Third Row Buildings(3)	Intermediate Rows of Buildings in Corrosion-Prone Areas(3)	Buildings Farther Landward(4)
Partially Sheltered Exterior Enclosures	Easy	• Avoid light gauge metal connectors • Use stainless steel connectors and fasteners • Use connectors with thicker galvanizing and replace when necessary	• Use connectors with thicker galvanized coating • **Best practice:** Use stainless steel connectors and fasteners	• Use connectors with code-required galvanizing • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel
Open Exposed Exterior Enclosures	Easy	• Avoid light gauge metal connectors • Use stainless steel connectors and fasteners • Use connectors with thicker galvanizing	• Use connectors with a thicker galvanized coating • **Best practice:** Use stainless steel connectors and fasteners	• Use connectors with code-required galvanizing • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel
Vented Enclosed Exposures	Difficult	• Use connectors with thicker galvanizing • **Best practice:** Use stainless steel connectors and fasteners • Use TPI-specified coatings or paints on truss plates • **Best practice for truss plates:** Use TPI-specified coatings over thicker galvanizing, or use stainless steel	• Use connectors with a thicker galvanized coating • Use TPI-specified coatings on truss plates near vents • **Best practice:** Use thicker galvanizing for all connectors; use stainless steel near vents or where salt accumulation is anticipated	• Use connectors with code-required galvanizing • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel
Unvented Enclosed Exposures	Difficult	• Use connectors with thicker galvanizing • Use TPI-specified coatings or paints on truss plates • **Best practice for truss plates:** Use thicker galvanizing or use stainless steel.	• Use galvanized connectors • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel	• Use connectors with code-required galvanizing • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel
Interior Living Space Enclosures	Difficult	• Use galvanized connectors • **Best practice:** Use thicker galvanizing than required by code or use stainless steel	• Use galvanized connectors • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel	• Use galvanized connectors • **Best practice:** Use connectors with thicker galvanizing than required by code or use stainless steel

The recommendations in this table are based on available research and are subject to change in future Technical Bulletins. Stainless steel connectors should also be considered a best practice in many of the areas listed in the table. However, due to practical and cost reasons, this guidance does not prescribe its use, although the galvanic corrosion chart (Figure 7) clearly shows that stainless steel (especially Types 304 and 316) is a superior performer for corrosion resistance compared to many other metals.

(1) See Section 7 for information on exposure classes.

(2) Ability to inspect/replace fasteners and connectors.

(3) 300 feet or less from the shoreline. Distances may vary depending on local climate. The width of corrosion-prone areas relative to the ocean should be determined from field observations, existing corrosion studies, and consultation with local building departments.

(4) Greater than 3,000 feet from the shoreline. Distances may vary depending on local climate and can extend much farther inland as identified by FEMA's Mitigation Assessment Team in Puerto Rico (FEMA, 2018b). The width of corrosion-prone areas relative to the ocean should be determined from field observations, existing corrosion studies, and consultation with local building departments.

11- References

1) **FEMA "Corrosion Protection for Metal Connectors and Fasteners in Coastal Areas**: in **Accordance with the National Flood Insurance Program** ***NFIP Technical Bulletin 8 / June 2019"***