

NORTH AMERICAN TOWER FAILURE

CAUSES AND CURES

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He is a member of the Society for Broadcast Engineers and the TIA/EIA Committee responsible for the composition of Standards governing antenna and tower design and fabrication. Since his affiliation with this committee, Mr. Davies has authored the ELECTRICAL GROUNDING AND CORROSION chapter of the current Code.

Certified by the Aerospace Industry Association and American Standard for Non-Destructive Testing, he has earned the title of Class III Ultra-sound Instructor Trainer.

Actively pursuing and participating in various tower-related projects, his work extends throughout the United States and abroad.

- TOWER DESIGN & STRUCTURAL ANALYSIS
- REINFORCING DESIGN & ANALYSIS
- FOUNDATION DESIGN & ANALYSIS
- ELECTRICAL GROUND SYSTEM ANALYSIS & DESIGN
- CORROSION: DETECTION, SOLUTIONS & PREVENTION
- PROJECT MANAGEMENT
- DUE-DILIGENCE INSPECTIONS
- MAINTENANCE INSPECTIONS

ABOUT CONSOLIDATED ENGINEERING, INC.

Incorporated in 1990, CEI has become a leading provider of engineering services for the commercial broadcast industry. Our engineering staff has provided design services for a multitude of fabricators on over 1000 broadcast towers projects. CEI offers structural analysis, electrical lightning and ground system analysis and design as well as corrosion-related services.

The following is a written version of my Power Point presentation bearing the same title, thoroughly explaining the major causes of catastrophic tower failure. Ancillary material emphasizing failure prevention has been added and offers viable methods for safeguarding existing structures and future projects.

ABOUT THIS REPORT

The facts and statistical data included in the following ***Tower Failure*** document are the result of considerable research, including an *in-depth* study using a compilation of data on reported broadcast tower failures occurring in North America dating back to 1960. The information contained in 96 different case studies collected over this 50-year span allowed us to determine the five (5) major causes responsible for towers failure. Not content with merely reporting the reasons for failure, we took this project to the next level by providing clear insight as to what could have been implemented to prevent these deleterious events.

Of particular significance is that our study was based *solely* on failures of broadcast towers and does not reflect similar events in the cellular tower industry, structures less than 200' or those occurring in other industries.

It became quite clear during the study that the 1960's and 1970's were a period of underreporting. Translated, the actual figures concerning failure rates are higher reflected during these two decades.

Sixteen years was the average number of years a tower remained in service. Quite a few structures failed during the construction phase or just after completion. Several stations reported multiple failures, and due to a variety of circumstances. One unfortunate station lost its tower *five* times!

TOP 5 CAUSES OF TOWER FAILURE

CONSTRUCTION ERRORS	31%
ICE	29%
SPECIAL WIND	19%
AIRCRAFT	11%
ANCHOR FAILURE	10%

Construction Errors, the #1 Cause of Tower Failure

31% of all tower failures fall into this category. Ironically, a lack of engineering-related oversight is primarily to blame. Poor judgment and/or misuse of basic engineering skills by crews during new tower erection and reinforcement of existing structures *significantly* increase the risk of failure. Many of these errors can be attributed to having little or no understanding when it comes to the temporary, *construction-related* forces applied to a tower and its foundation, during erection and reinforcement projects.

California AM Tower Falls during Construction

March 18, 2008 – “On Saturday, KFI-AM personnel welcomed the long-awaited construction of their 684-foot guyed tower in La Merida, CA. However, at 2:04 P.M. today, they watched in disbelief as the new tower crashed to the ground as a tower crew prepared to pull tension on the third level of seven guy wires. A tower rigger employed by the erection contractor, Seacomm Erectors, Inc. of Sultan, WA, received minor injuries. The tower was engineered and manufactured by Magnum Towers, Inc. of Sacramento, CA.”



Joplin, MO -- “About half of the KSNF-TV tower came down this morning during an antenna change. A large section of the broadcast tower fell, crushing a vehicle and causing damage to several homes in the area” *Joplin Globe, May 8, 2009.*



On March 21, 1997, “*KNOE-FM* suffered a catastrophic collapse of its broadcast tower. The 1,989 foot tower, roughly 545 feet taller than Chicago’s Sears Tower, collapsed as a result of a maintenance crew’s failure to install a temporary support structure during the replacement of diagonal braces. Of the three workers on the tower at the time of the collapse, one was killed, one fell into a satellite dish about 12 feet above the ground, and the third walked away, virtually unharmed.”

THE THREE MOST COMMON REASONS FOR TOWER FAILURE DURING CONSTRUCTION ARE:

- Insufficient Rigging Plan
- Inadequate Reinforcement for Construction Loads
- Guy Wire Slippage

1. INSUFFICIENT RIGGING PLAN

It is not uncommon for a contractor to have an insufficient or even *non-existent* **Rigging Plan** to serve as a guide during tower erection or modification. An engineered, step-by-step plan outlining the *entire* construction process should be developed before commencing *any* tower work. Such a plan is critically important for ensuring proper technique and equipment are used during each operation, as well as to ascertain whether the structure in question can adequately support the anticipated construction loads.

Rigging plans may be extremely detailed or very simple depending on the lift requirements and available equipment, but should always be *mandatory*. Separate rigging plans are not necessarily required for each individual lift. If lift conditions are identical or very similar to previous lifts, a pre-qualified plan may be duplicated simplifying the time and effort involved in plan preparation.

Further explanation and rigging plan templates can be found in the **TIA-1019 Structural Standard, annex D**

2. INADEQUATE REINFORCEMENT FOR CONSTRUCTION LOADS

Construction loads must be considered during 1) the design phase 2) new construction and 3) when modifications to an existing structure are made. These include:

- a) **Structure Dead Loads** (weight), **Live Loads** (wind), **Construction Equipment Loads** (gin pole and rigging block loads) and **potential unequal loading from guy wires** (slippage). Live Loads from ice or earthquake for construction activity are typically not considered.
- b) Loads are classified as either *Operational* (during construction activity) or *Non-Operational*. Operational conditions such as during lifts, assembly or dis-assembly of the structure or manipulation of guy wires can occur with effective wind speeds of up to 30 mph. The structure must be capable of withstanding wind forces of a minimum of 45 mph up to 90 mph, depending upon the duration of the construction project. The structure in any assembled state must meet the following '*non-operational*' wind speeds:

Construction Period	Minimum Factor
Continuous work period:	0.50 (0.5 x 90 mph = 45 mph)
Less than 24 hours: (overnight conditions)	0.60 (54 mph)
24 hours to 1 week:	0.67 (60 mph)
1 week to 6 weeks:	0.75 (67.5 mph)
6 weeks to 6 months:	0.80 (72.0 mph)
> 6 months:	1.00 (90 mph)

[Wind Speeds are 3-Second Peak Gust]

3. GUY WIRE SLIPPAGE

The potential for guy wire slippage during new construction or during guy wire change of an existing structure is oftentimes dependant on the tools and equipment used.

Guy wire slippage causes unplanned and often unequal forces to be placed on the structure. In many cases, a dynamic change in the loading condition of the tower connections results.

Guyed towers are typically designed so the majority of the vertical leg members are in compression, experiencing virtually no tension forces.

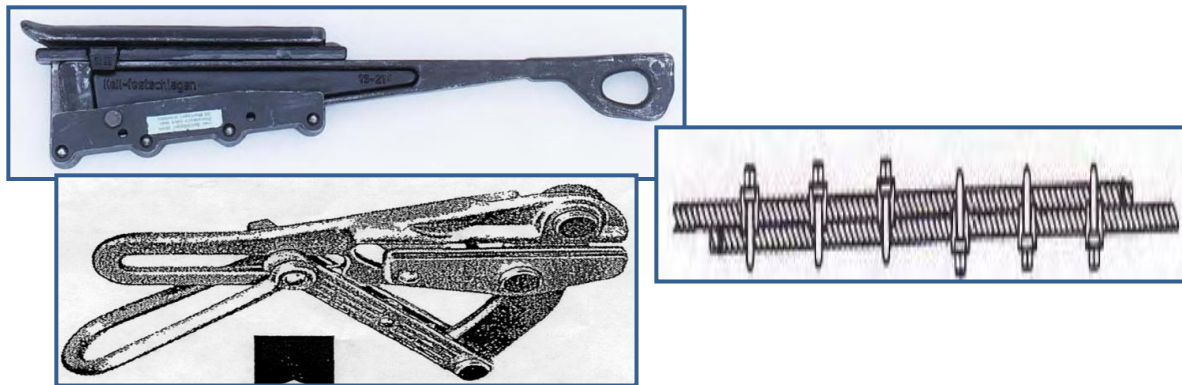


Consequently, the loss of a *single* guy wire during erection of a new tower or when reinforcing an existing tower, will put unexpected tension loads on one or more tower legs, often resulting in failure.

Rev G, initially released for publication in July of 2005, is the *latest* revision of the **ANSI/TIA-222 Standard “Structural Standards for Antenna Supporting Structures and Antennas”**. The revision became mandatory on January 1, 2006. This was the first version of the tower Standard to specify a minimum leg splice tensile strength and define a procedure to evaluate a “broken guy” condition. The **ANSI/TIA-1019A** is the first Standard to specifically address guy slippage or sudden release during construction.

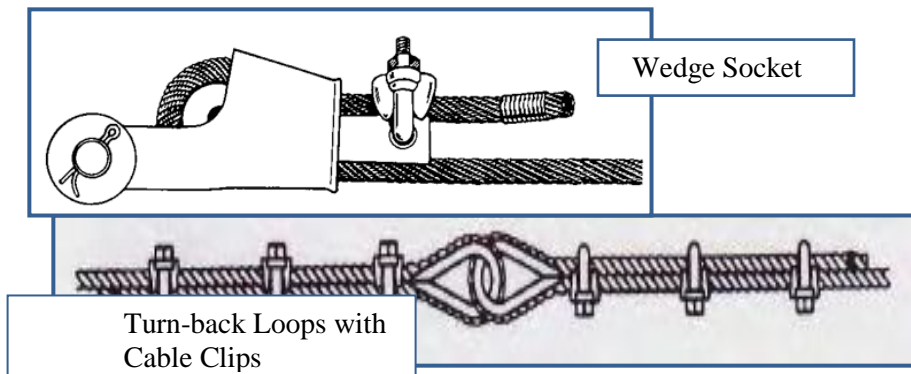
Without sufficient guidance, these omissions by some tower designers resulted in insufficient weld capacity and/or insufficient connection bolt capacity at the leg splice plates. The insufficiencies oftentimes resulted in tower failure when slippage or guy release occurred.

The following tools and attachments *known* to slip guy wire:



(In-line cable splices and Friction type grips without turn-backs)

Illustrations of *recommended* tools and attachments are shown below:

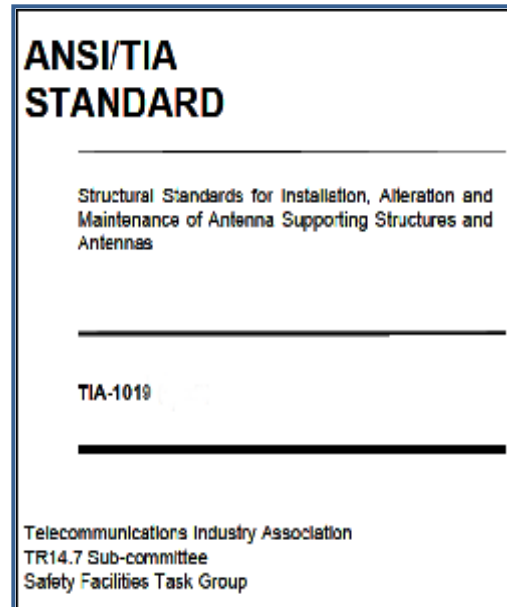


CURING CONSTRUCTION-RELATED TOWER FAILURE

Construction crews are routinely required to make engineering-related decisions, yet most lack training and/or formal education to effectively do so. More and more resources are becoming available to enable construction personnel to maintain a safe and productive work environment.

The **ANSI/TIA 1019A Construction Standard** is *the source* for information and guidance relating to tower erection and maintenance services. The publication provides **Structural Standards for Installation, Alteration and Maintenance of Antenna Supporting Structures and Antennas**.

Compiled by the **Telecommunications Industry Association TR14.7 Subcommittee, Safety Facilities Task Group**, the Draft of the **TIA-1019** has been quoted as providing the “**BEST PRACTICE**” guidance for tower erection and maintenance service. This new Standard provides specific guidelines for tower erectors when applying loads to towers during erection or reinforcement. *Securing the services of a qualified, hands-on engineer to assist with your construction plan and provide over-site of the entire process is the best alternative.*



A broad range of topics are addressed in this Standard.

- Construction Considerations
- Gin Pole Operation and Use
- Loads on Structures During Construction
- Gin Pole Analysis and Design
- Gin Pole Construction
- Procurement and User Guidelines
- Rigging Plans
- Wire Rope Connections
- Evaluation of Tower Sites

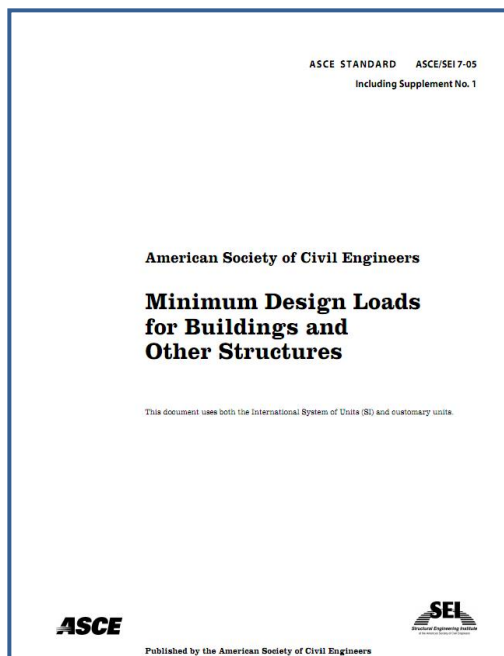
Note: Adherence to this standard could have avoided 90% of construction-related tower failures.

#2 Cause of Tower Failure is *Ice and Wind with Ice*, accounting for 29% of all tower failures during the 50-year span included in our study.

WATERLOO, February 24, 2007 - The upper half of the **KHKE** tower collapsed during an ice storm. "*There was over an inch of ice on the tower, and coupled with 30- to 40-mph winds, it just toppled.*" said KHKE and KUNI General Manager Wayne Jarvis.



Prior to **Rev G**, older tower design codes offered little if any information regarding ice and the resultant effects this additional weight and stress placed on towers. Subsequently, there was nothing mandating that **ice and wind with ice** be addressed during the design phase. **ASCE 7-05 Standard** significantly reorganized provisions for seismic design of structures, as well as revisions in the provisions for determining live, flood, wind, snow, and atmospheric ice loads.



Historically, guidelines taking realistic amounts of ice for a particular region into consideration, based on climate and the appropriate winds that should be applied with ice for these ice-prone regions of our country, were virtually non-existent. **Rev G of ASCE 7-05 Standard** brought these critical guidelines.

Ice accumulation on a structure increases *both* the area and weight, resulting in additional force. Increased surface area captures more wind, equating to more wind force on the tower and appurtenances.

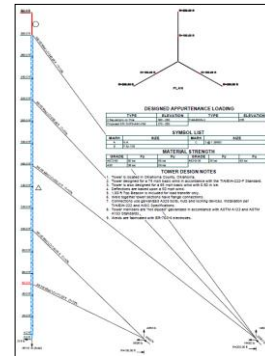




In reality, Ice and Wind with Ice *may* be the culprit in a significant number of tower failures. Logic tells us that if proper considerations had been made, following published guidelines during design, fabrication and installation, the #2 cause of tower failure may NOT be Ice or Wind with Ice.

Comparison of Previous Codes to “G” Code

- 350 foot “Utility” guyed tower
- Typical FM tower
- Designed using the “C” code, **no ice**
- Analyzed using (1) “F” Code, with ice
- Analyzed using (2) “G” Code, with ice



2

30 psf-No Ice

The now defunct Utility Tower Company designed and fabricated the above tower (diagram above) using the specifications set forth in the **EIA-222-C** design standard, in which no mandates for accumulation of ice were written.

The tower is analyzed using both the **TIA/EIA 222-F** code and the **ANSI/TIA 222-G Standard**.

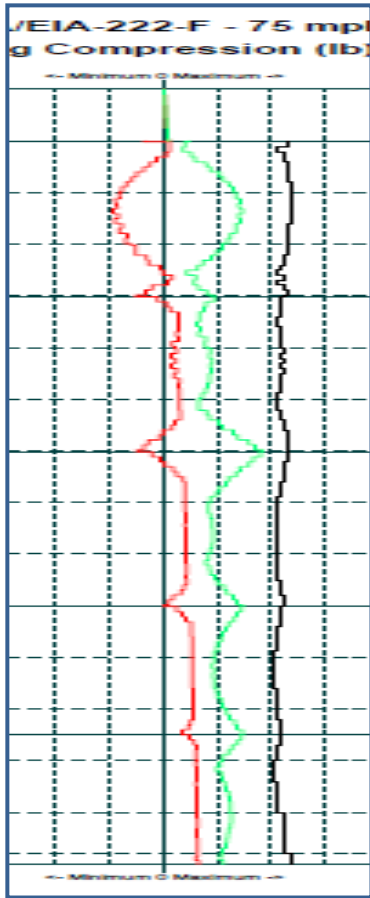
The following graphic diagrams contrast the differences of designing a tower using the **EIA-222-C**, **TIA/EIA-222-F** and the **ANSI/TIA 222-G** codes of the industry tower Standard.

When the tower was analyzed using the original design code, **EIA 222-C**, no structural deficiencies were noted, but ice accumulation was not considered, either.

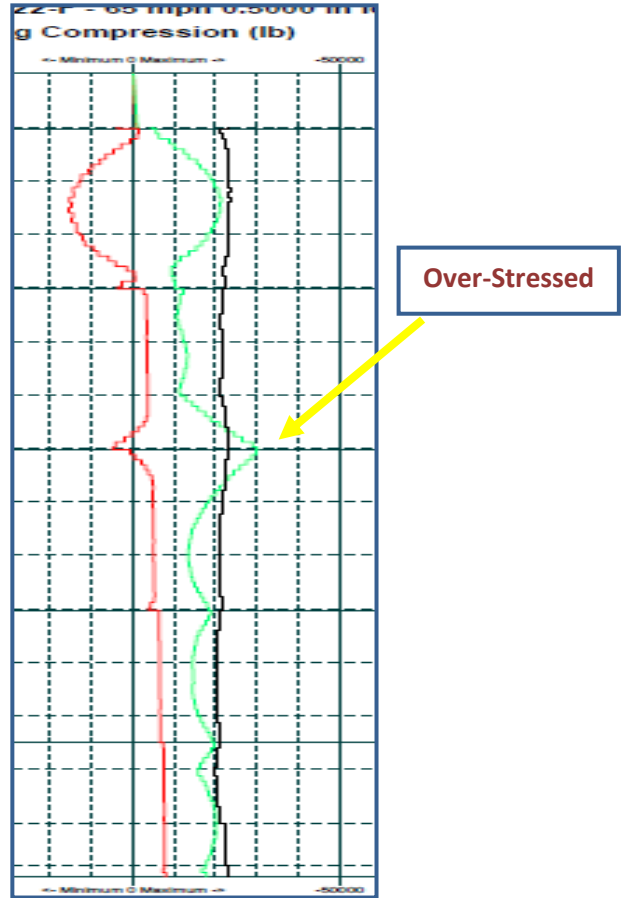
In analyzing the tower using the **TIA/EIA 222 F Standard**, again the tower leg members were well within their allowable capacity. However, using the **F Standard’s suggested ½” of radial ice with 87% of the one-in-50-year** design wind speed, the tower legs were over-stressed in the mid-section of the tower.

In the following diagrams, the green line indicates the tower leg compression stress. The heavy black line indicates the tower leg capacity. The diagram on the left portrays the tower leg stress to capacity in the “no ice” condition. The diagram on the right portrays the tower leg stress to capacity considering the optional and “purchaser specified” ice condition.

75 mph with No Ice:



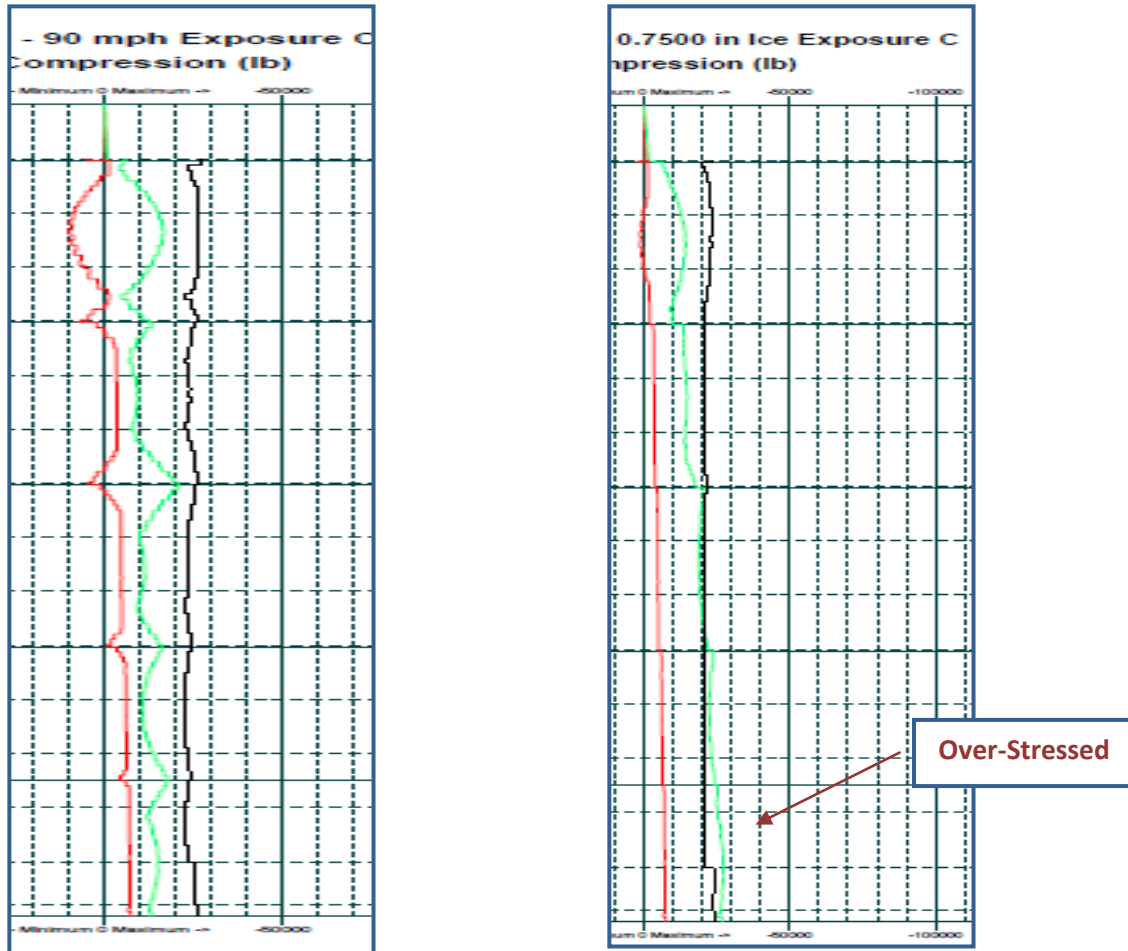
65 mph with 1/2 inch of Ice:



Note *above right*, the over-stressed condition, using the TIA/EIA-222-F reduced wind speed and 1/2 inch of ice, is clearly visible in the mid-section of the tower.

Compare this to the same tower analyzed using **Rev G of the TIA/EIA-222 Standard**, shown below.

Rev G 90 mph (3 sec) = Rev F @ 70 mph Rev G 40 mph (3 sec) with ¾ inch ice escalating



Using the **Rev G**, the tower legs are no longer over-stressed in the mid-section, as was the case using the older **F Standard**. Now, stress is indicated in the lower section of the tower legs.

The high wind speed of **222-F** with ½ inch of ice may also cause one or more levels of upper tower guys to be replaced, in contrast to using **222-G** tower wind speed with more ice, which would find the guys satisfactory.

If the original tower was reinforced to meet the less accurate ‘**F**’ code load, this reinforcement would have created additional stress to those portions of the tower previously deemed insufficient using the ‘**G**’ code analysis. In other words, reinforcing this tower to meet the deficiencies indicated in the “**F**” Standard analysis would actually increase the likelihood of failure. Why?

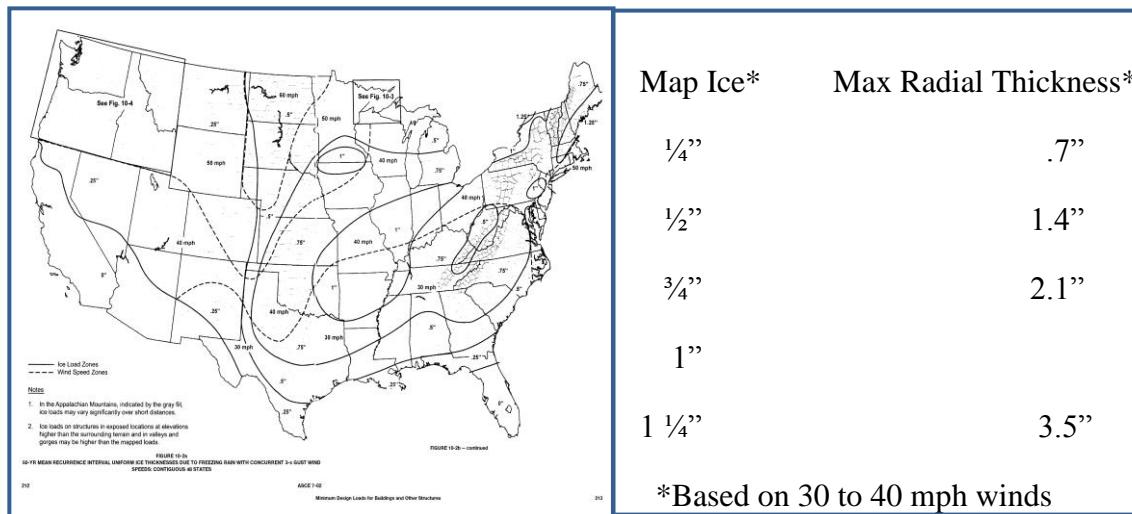
The case study on the previous page exemplifies deficiencies of previous design codes. Many areas of the country have greater ice thickness accumulation potential than ½ inch radial. In addition, the wind speeds with this greater ice thickness is much less than what **222-F** requires. The discrepancy in ice with wind loading of previous codes has resulted in most existing towers having design flaws. Even if Ice was stipulated by the tower purchaser, the amount and resulting increased weight were insufficient compared to actual icing conditions now considered.

Cure for Ice and Wind with Ice: Revision G of the ANSI TIA/EIA-222

Revision G of the ANSI/TIA 222 Standard, effective January 1, 2006, introduced a **mandatory ice loading** specific for local county criteria. This revision is based on tower height, elevation and exposure. Through understanding what was lacking in previous design standards regarding Ice and Wind with Ice, it's clear to see how failures attributed to insufficient design and those failures blamed on Mother Nature, in this case, *Ice and Wind with Ice*, become increasingly difficult to distinguish.

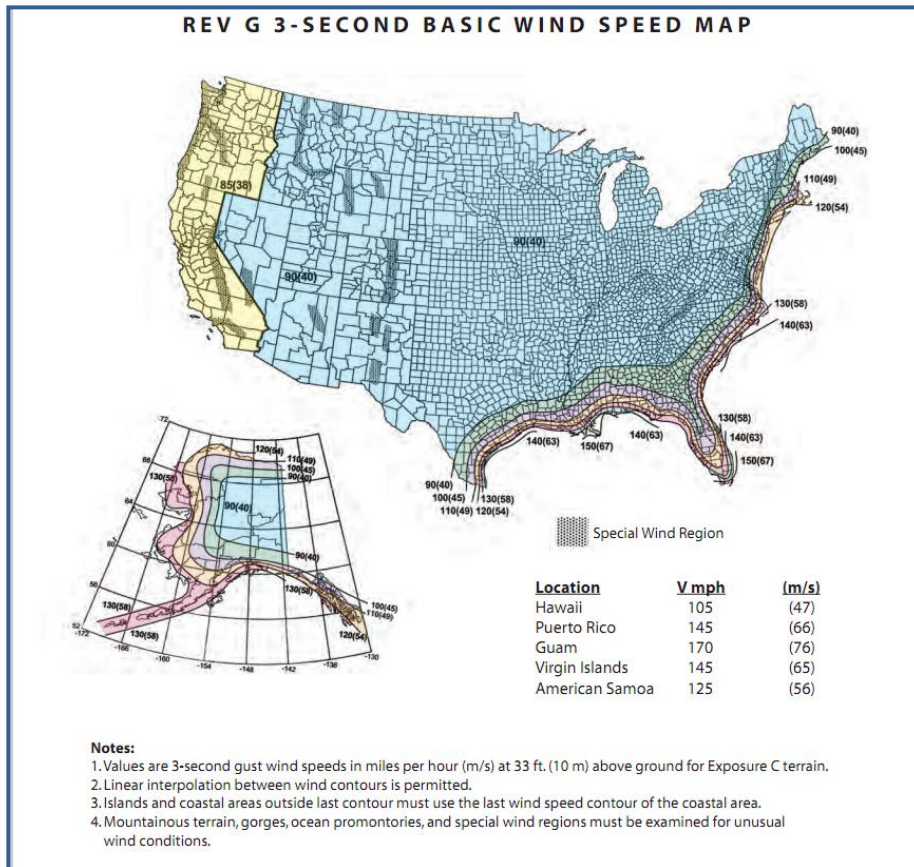
Annex A of the 222-G provides the broadcast tower owner and tenant a list and explanations of the procurement specifications required for purchasing a new tower and for purchasing an analysis/modification for existing towers. The primary items necessary for inclusion in the procurement specifications for (1) new towers and for (2) analysis/modification to existing towers, with respect to Wind and Ice are:

- ▶ Structure classification
- ▶ Three-second-gust basic wind speed and design ice thickness
- ▶ Exposure category
- ▶ Topographic category



3-Second-Gust Basic Wind Speed Map and Design Ice Thickness, above

Annex B of the 222-G includes a county listing of minimum basic wind speed without ice, shown below:



Resources are available for broadcast owners and tenants to estimate and fairly easily determine the feasibility of upgrading their tower from the original tower design parameters to **Revision G of the 222 Standard**. Similarly available are methods for determining the feasibility of equipment and/or inventory changes to a tower. *Contact CEI for detailed information and pricing.*

Special Winds constitute the #3 Cause of Tower Failure

Hurricanes, Tornadoes and Straight Line Winds account for approximately 20% of all disasters. As with Ice and Wind with Ice failures, sub-par design, fabrication and installation techniques are frequently to blame. The design of many structures is now considered obsolete due to inadequate and/or inaccurate wind speed maps and oversimplified, outdated methods of calculating wind force.

“On Saturday, May 10, 2003, a strong storm moved through the Midwest. A tornado touched down in Peoria, IL. Three out of the four towers were toppled.” See photo, right

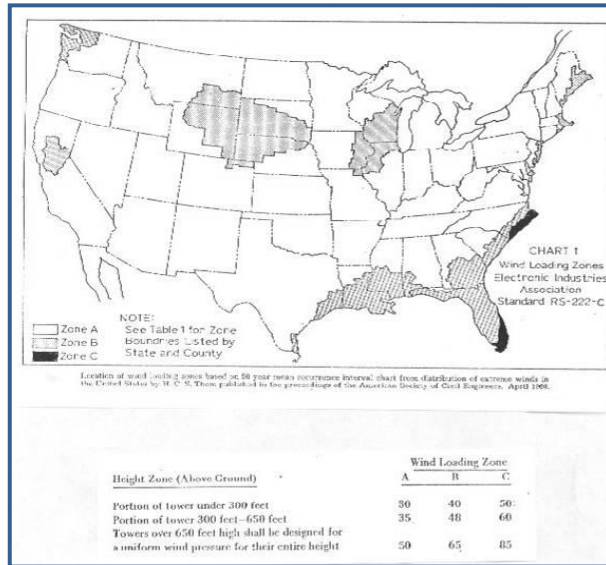


“About 10:30 Wednesday night (8/23/00), a thunderstorm with straight line winds in excess of 60 mph moved through Mexico, MO.” Gary Leonard: KXEO and KWWR's tower failure August 2000. See photo, left

Keep in mind, minimum design wind criteria for this area was 70 mph, fastest mile wind speed. According to the news report, the tower failed during a 60 mph wind gust (3-second average wind speed) when the tower was allegedly designed to meet a 70 mph fastest mile wind speed which is equivalent to an 85 mph gust or 3- second average wind speed!

In other words, the tower should have been able to withstand a gust or 3-second-average wind speed of 85 mph, yet fell during a 60 mph gust. Was this tower failure really a result of excessive wind speed? Probably not, but insurance companies won't pay when poor designs or improper maintenance are to blame.

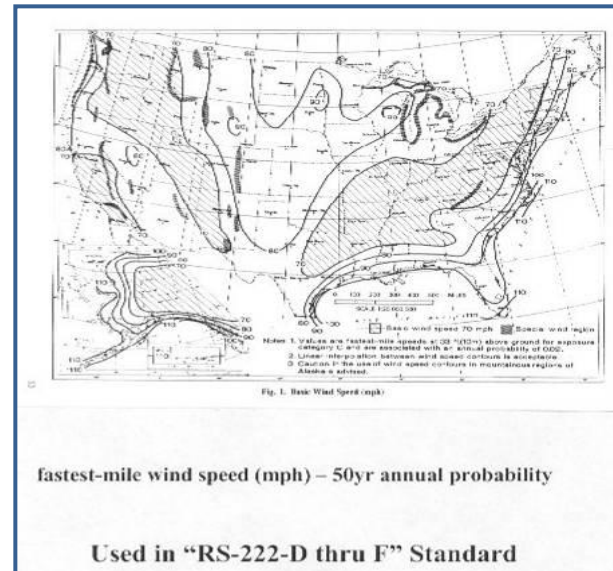
Outdated Wind Maps and Oft-Ignored Design Variables Hampered Earlier Tower Designs



Compare the two maps, *shown left and below*. The map on the left was published in the **EIA RS-222 (A-C)**, the Standard from 1949 to 1985. The **D thru F Standard**, implemented in 1986, brought us the *Fastest-Mile Wind Speed*, see below.

Explanation and Expression of Wind Speeds and Wind Force

The **EIA/RS-222-C** Standard converted a ‘basic’ wind speed to a wind pressure. The country was divided into three separate areas, each with differing wind pressure requirements. Zone A required a 30 psf design. Zone B required a 40 psf design and Zone C, a 50 psf design. Tower designers weren’t required to determine the appropriate wind speed, only the prescribed wind pressure, as dictated by the map, shown above.



The **EIA/RS-222-D through F Revisions** eliminated the simplified three zones and their associated wind pressure by substituting a ‘wind map’ prescribing the appropriate wind speed according to location. Wind speed was referred to as *Fastest Mile Wind Speed*, or the average speed measured during the passage of one mile of wind. In other words, the average time between the peak and lull wind speeds fluctuated as a function of the wind’s velocity. For example, a 60 mph fastest mile wind speed would represent an average of the fluctuating wind velocities for 60 seconds. This is not the wind speed reported on the 6 o’clock news. Nor is it what county building officials expect to see displayed on submitted tower designs.

The **ANSI/TIA-222-G Standard** revision adopted the *Peak Wind Speed* design method: a *3-second average* of the recorded peak wind velocities. It is in keeping with the **International Building Code (IBC)** requirements recognized by most state and local building authorities, and the preferred method for accurately calculating wind velocity.

Simplified, a design using the **C Standard** for Zone A wind speed is equivalent to an **F Standard** design using 70 mph wind speed, which is comparable to a **G Standard** design for 85 mph, exposure 'C' wind speed design.

Exposure Categories

Another example of tower design variables not mandated in previous Design Standards. Exposure categories relate to ground roughness which may affect wind velocity by reducing or increasing the wind speed, deviating from the wind velocity specified in **Appendix B** of the Design Code.

It is important to have a good understanding of Exposure Categories and their effects when analyzing an existing tower or during the design phase of a new tower. Historically, the burden was placed on the *purchaser* to determine and note appropriate Exposure(s).

The following information was included in the *Power Point* presentation on tower failures and provides detailed descriptions of the three **Exposures (B, C and D)**, none of which were addressed in previous Standards and Revisions.

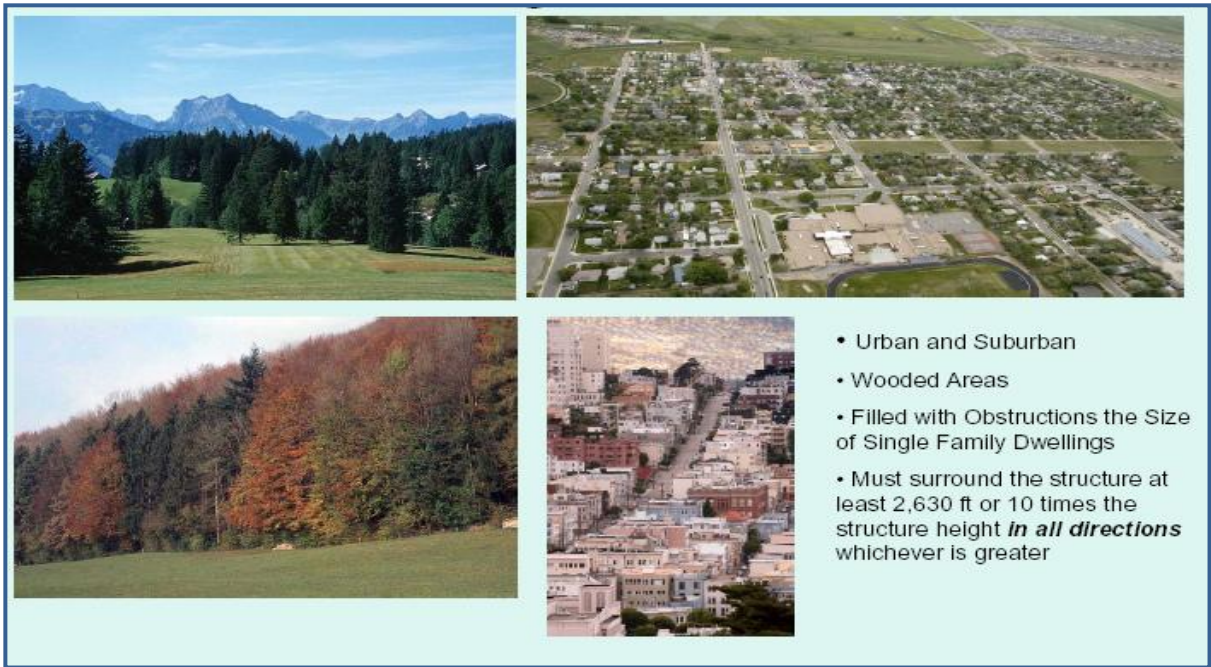
2.6.5 Exposure Categories

2.6.5.1 General

An exposure category that adequately reflects the characteristics of ground surface irregularities at the site shall be determined. Account shall be taken of variations in ground surface roughness that arise from natural topography and vegetation as well as from constructed features. The exposure category for a structure shall be assessed as being one of the following:

1. **Exposure B:** Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. Use of this exposure shall be limited to those areas for which terrain representative of Exposure B surrounds the structure in all directions for a distance of at least 2,630 ft [800 m] or ten times the height of the structure, whichever is greater.
2. **Exposure C:** Open terrain with scattered obstructions having heights generally less than 30 ft [9.1 m]. This category includes flat, open country, grasslands and shorelines in hurricane prone regions.
3. **Exposure D:** Flat, unobstructed shorelines exposed to wind flowing over open water (excluding shorelines in hurricane prone regions) for a distance of at least 1 mile [1.61 km]. Shorelines in Exposure D include inland waterways, lakes and non-hurricane coastal areas. Exposure D extends inland a distance of 660 ft [200 m] or ten times the height of the structure, whichever is greater. Smooth mud flats, salt flats and other similar terrain shall be considered as Exposure D.

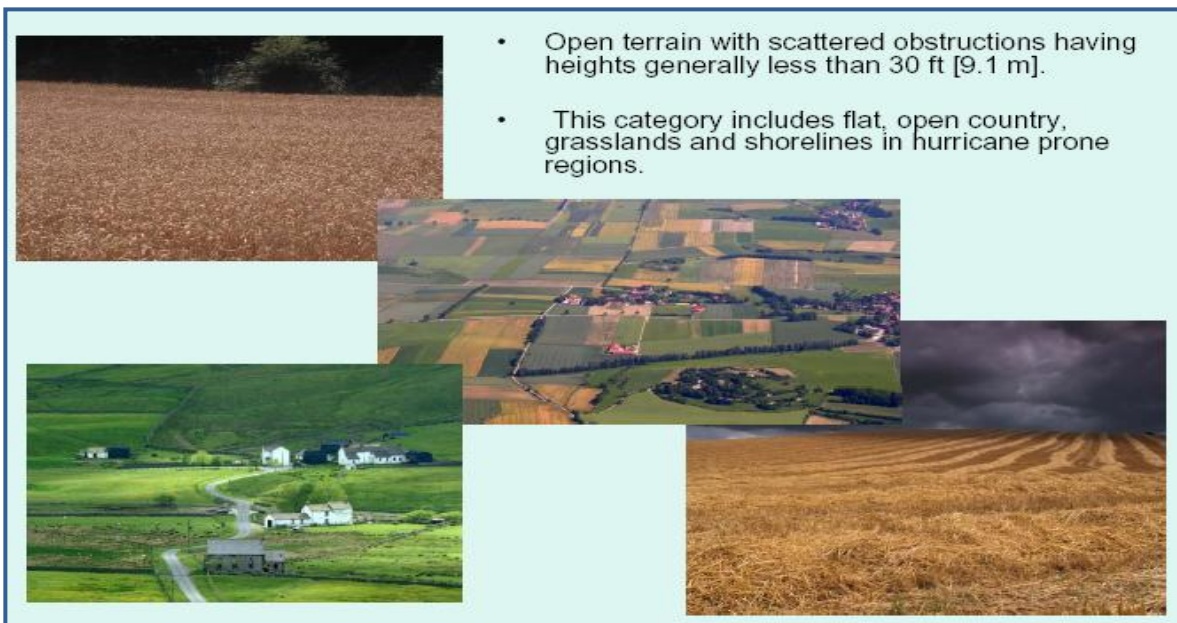
Exposure B: Smaller Building and Trees



The photographs, *above*, illustrate variations in ground roughness with respect to urban, suburban and wooded areas. The wind at ground level is reduced compared to Exposure C. This reduction diminishes with height, making the overall reduction less significant for taller structures.

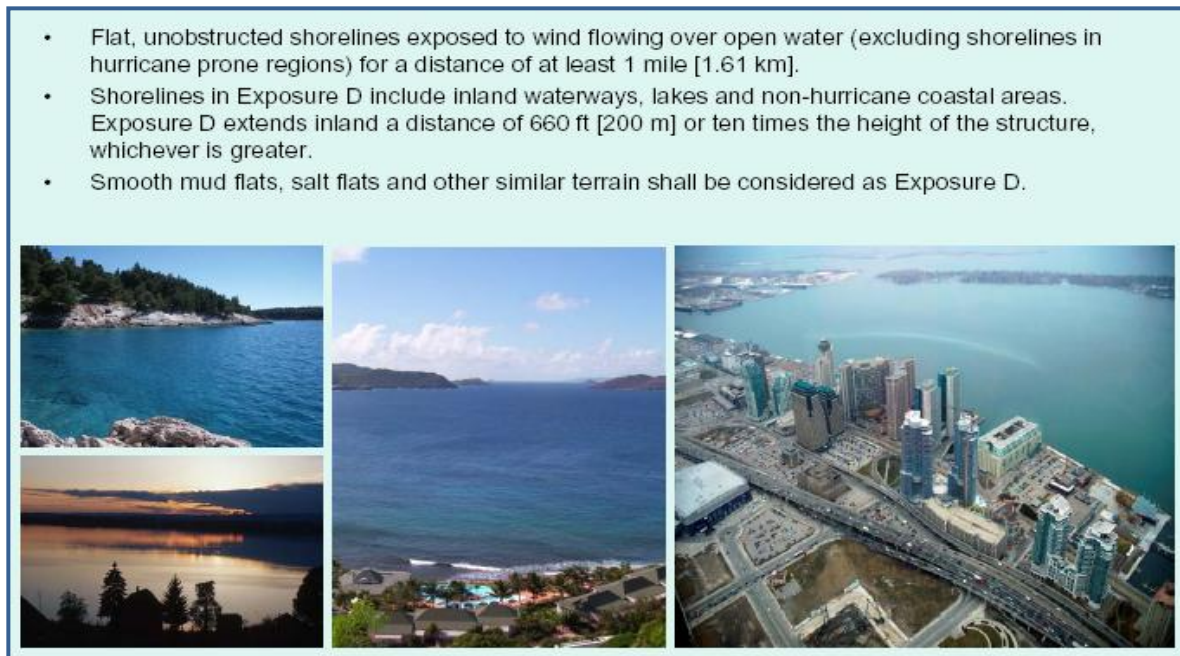
Exposure C: Open Terrain

Open Country and Grasslands are included in this category, see photo, *below*.



Exposure D: Unobstructed Shorelines

Flat, unobstructed shorelines exposed to wind flowing over open water, mud and salt flats are included in Exposure D, with the characteristic of increased wind loads at ground level compared to Exposure C. *Photo, below.*



Topographic Categories and Terrain Variables

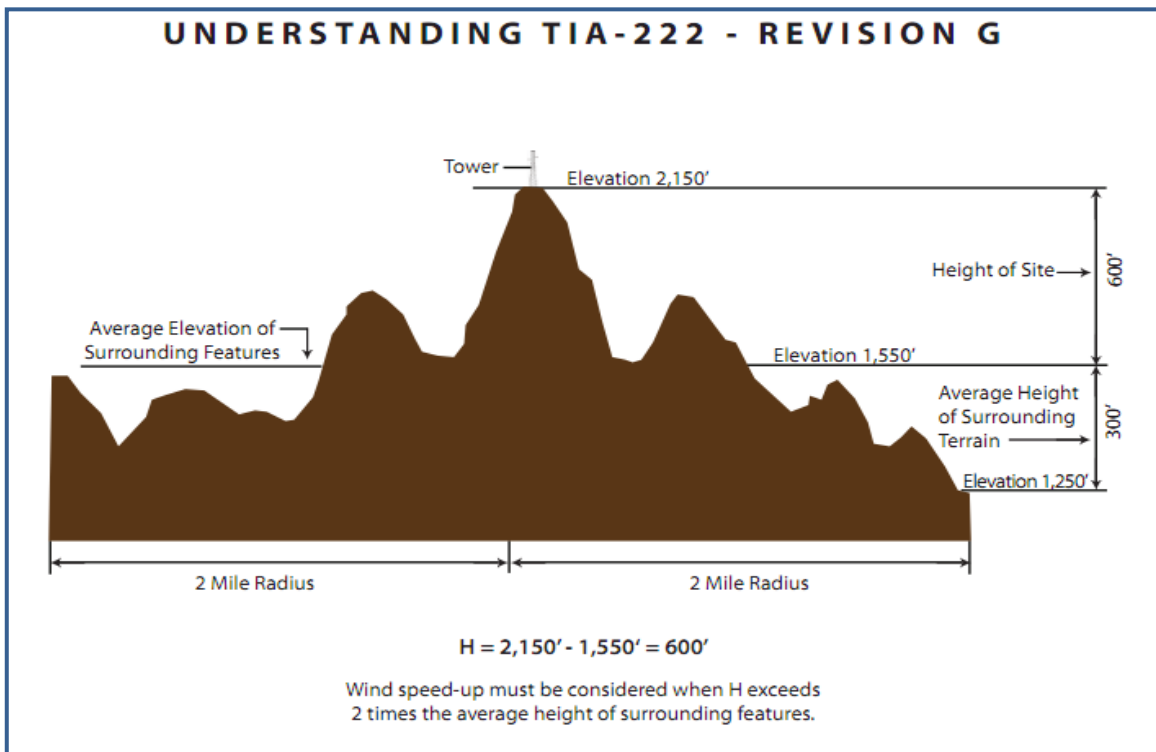
The inclusion of **Topographic Categories**, also referred to as **Terrain Variables** in **Revision G** is one example of design parameters the ‘C thru F’ code failed to mandate.

There are five (5) categories used to determine increases in wind loading for sites situated on hills and other elevated areas (not including buildings). The topography or *shape* and relative height of a site determines the increased wind loads. Choosing the correct category can significantly affect both the capacity and cost of your tower.

Height is not equivalent to elevation. Height above the surrounding terrain must be specified to properly determine the increase in wind loading.

- 1) **Category 1:** Flat or rolling terrain that does not require wind loading.
- 2) **Category 2:** Gently sloping terrain or escarpment. Wind loads at the crest are 2.0 times the wind loads for a flat site. Height for the category is the difference between the upper and lower levels, with wind loads applicable for structures located in the upper half of the sloping terrain.

- 3) **Category 3:** Sites at the top or upper half of a hill. Wind loads at the top of a hill are 2.3 times those on flat land. Height for a hill is the difference in elevation between the top and bottom of the hill.
- 4) **Category 4:** Sites located at the top of a ridge have a wind load 3 times those for flat sites. Height for ridges is the difference between the top and bottom elevations of a ridge.
- 5) **Category 5:** The category reserved when site-specific investigations must be performed to determine wind loading. The site can't be categorized using 1-4 above, because of unique or unusual conditions.



“In every wind induced tower failure I have investigated, the tower would not have passed the current design code” says Forensic Engineer, Ernie Jones, PE, of Consolidated Engineering, Inc.



DUE DILIGENCE IS REQUIRED!

It is imperative to “get it right” when using these Site-Specific Tower Design Parameters. Don't rely on your tower salesman to define what is in *your* best interests. A proactive approach is necessary when determining the specifications to be implemented for your new tower *or* with analysis of an existing structure. **Don't hesitate to ask for guidance.** Consulting Engineering firms will provide this service. The cost of obtaining Structural Specifications (for a new tower or tower reinforcing) ranges from \$250.00 and \$2,500.00, depending upon the size of the project. The **ANSI/TIA-222-G Standard** is not exclusive to future projects. ***Existing towers should be analyzed and brought up to the Standard, when indicated.***

Keep in mind, the Standard specifies the ‘*minimum*’ criteria required during design and fabrication. Owners should augment the minimum specifications with *performance-related* design criteria. One example is with using increased tower twist and sway requirements, intended to enhance antennae performance. ***Contact CEI for antenna performance-based tower design recommendations and specifications, as well as guidance in determining the correct environmental factors.***

Basic guidelines when new towers are under consideration:

- Always provide site-specific bid specifications
- Design to **Rev-G Standard**
- Use site-correct variables in specifications, not *default values*
- Recognize “minimum requirement” and substitute performance requirements
- Use **AISC Certified Providers**

When working with existing towers, solutions for ice and wind always include the following:

- Remove all unused appurtenances
- Structural analysis using **Rev-G**
- Reanalyze when changes are considered
- Annual inspections, including anchors
- Preventative maintenance

Wind and/or Ice is *NOT* Always to Blame

December 11, 2007 © By Phillip Walzer “*The parent company of WSKY-TV has sued the builder of a tower that toppled in 40 mph winds in Camden County, N.C., in March, saying its work was shoddy from start to finish.*” Walzer commented further saying “*The suit reads like a lament against a sloppy contractor.*”



There is much to consider when discussing various reasons for tower failure. A poorly constructed tower may offer many years of service before tumbling to the ground. Although the failure may officially be attributed to environmental factors, for example, wind and/or ice, **design and fabrication errors**, independent of or coupled with, **poor construction** are more often the root cause of failure.

We can categorize these types of failures as either ***Provider-Induced or Owner-Induced***

Provider-induced failures include those caused by:

- *Design flaws*
- *Fabrication flaws*
- *Installation flaws*

Owner-induced failures include the following:

- *Overloading*
- *Failure to properly maintain*

Design Flaws

The **WJJY incident in Bluffs, IL** is an excellent example of *both* poor design and overloading.

“Though it would appear ice was the cause of the failure, this was not the case. This illustrates a failure to accurately plan for climatic conditions typical in this region, coupled with an underestimation of the antenna wind load. The tower collapsed during a massive ice storm exposing a serious design flaw in the tower. The tower had been designed for a much lighter antenna and couldn't handle the additional weight of the ice or the wind load. Ironically, another station, WAND-TV, also in Illinois, suffered an almost identical failure the same morning as WJJY when the top of their 1000' tower crashed to the ground. An upper section of antenna broke loose, falling through the guy wires. Both stations had similarly designed towers installed by the same company. Again, the tower was not designed for the heavier antenna load and the ice revealed the flaw in design.”

Fabrication Flaws

Fabrication refers to the methods used to piece a tower together in the shop. The margin for error with respect to fabrication is very small. These startling photos, borrowed from my Power Point presentation, were taken after a tower collapsed. They illustrate just *one* of the many possible types of fabrication errors. The reason for collapse was *insufficient weld penetration* causing a tower leg to break free from the flange. *See photos, below.*



Installation Flaws

The photograph, *below*, is an *extreme*, yet not uncommon example of an *Installation Flaw*. Failure to remove the casing after the concrete was poured reduced the foundation skin friction and uplift capacity.



Cures for Provider-Induced Failures

The importance of securing a qualified fabricator and installer can't be over-emphasized. Never trust your project to an uncertified provider. Consider using only American Institute of Steel Construction (AISC) Certified Companies. AISC "member" and AISC "compliant" is not equivalent to being AISC "certified". To determine if a company is currently certified visit www.aisc.org, then click "find a certified company".



Additional *proactive* measures should be conducted when any type of tower work is considered.

1. *Insert a copy of "Adherence to ANSI/TIA 1019 and CPL2-1.36 Standards" into all specifications and contracts*
2. *Qualify you contractor*
3. *Request copies of insurance*
4. *Request copies of Engineered Rigging Plans prior to commencing work*
5. *Check references*
6. *Don't hesitate to ask questions. If something doesn't appear right, it probably isn't*

Cures for Owner-Induced Failures

1. Develop and Implement an *Antenna and Transmission Line Management Program*, including:

- a. Accurate Equipment Inventory. Often a new tenant installation will require a structural analysis. Knowing what is on your tower will increase the accuracy and reduce the cost of this study.
- b. Document tenant leases(s) and determine the lease matches the actual installation. Make sure the lease accurately describes the antenna/line wind load and verify the data is correct.
- c. Reorganize transmission line runs to minimize wind load. This can include grouping lines to take advantage of wind shielding. Or, often unused transmission lines and equipment are abandoned and left on the tower.
- d. Be reasonable in your tower expectations. Compare the original design documents to the present tower loading conditions.
- e. Conduct a structural analysis *prior* to any major appurtenance change.

2. Formulate a *Routine Maintenance Plan* (Refer to **Annex J: Maintenance and Condition Assessment of the ANSI/TIA 222 G Standard for details):**

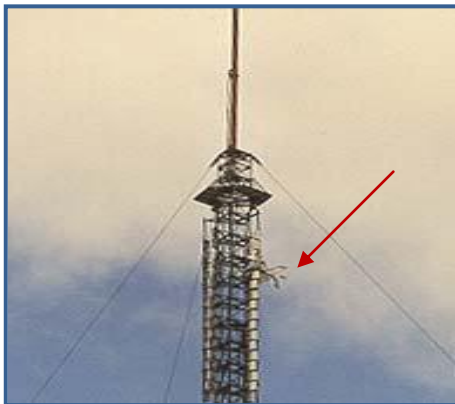
- a. Plan to perform inspections *at minimum* every 2 years
- b. Inspect the tower *immediately* following *any* severe wind or ice events *and* upon completion of any new installations. You may be surprised at your findings after allowing the lease holder or his crew access to your tower.

3. *Heed the recommendation(s) contained in the inspection report!* You paid someone to climb and document your tower's condition. Don't then ignore their reasonable and documented recommendations.

Aviation-related incidents, accounting for just over 10% of all failures, are the 4th leading cause of tower failure.

Statistically, no single type of aircraft is more vulnerable or likely to collide with a tower than another. Helicopters, single-engine planes and military aircraft have proven *equally* hazardous to broadcast towers. Time of day or daylight *versus* darkness show no pattern of increased incidence. Surprisingly, there is no correlation between the presence of any particular type of lighting system and collision. When combined and scrutinized, these factors create a bit of a challenge when addressing aviation issues.

UPPER QUEBEC PROVINCE, CANADA – “On Sunday, April 22nd 2001, 38-year old Gilbert Paquette was killed when his single-engine Cessna 150 struck a 1,217-foot tall communications tower while flying in heavy fog during daylight hours over a remote region of upper Quebec Province.” Note the wreckage near the top right portion of the tower.



La Mirada, CA- “On Sunday, December 19, 2004 at 9:45 a.m. PST Jim and Mary Ghosop were killed when their rented Cessna 182P single engine airplane, travelling from the El Monte airport to Fullerton Municipal, struck KFI's transmission tower. The solid steel truss, originally built in 1948, collapsed upon itself, falling primarily into a parking lot north of the site. The crash occurred on a sunny, cloudless day.”

Incidentally, on Tuesday, March 18, 2008 KFI's replacement tower collapsed while under construction. “Approximately 300' of the total 684' had been erected when a guy wire support failed, causing the tower to tip over the opposite direction. No major injuries and limited collateral damage resulted.”

DOERUN, GA - “A military helicopter has crashed after striking the upper portion of WFXL's 1,000-foot tall TV tower near Doerun in Colquitt County. The collision caused a guy wire to break loose, opening the possibility that the steel tower could fall.” And it did.

St. Petersburg, Florida- “On April 25, 2000 a medical helicopter flew into a guy wire on WRMD's 198m (650') tower. Three people were killed. The incident happened during daylight hours in clear skies.”

Cures for Aircraft-Related Failures

Without question, make certain your tower is registered with the FAA, even if you are not the owner, but renting the structure. Tower registration can be confirmed through the following URL and entering your coordinates: www.wireless.fcc.gov/antenna.

The following are basic guidelines for tower marking, as provided for in the **FAA Advisory Circular AC-70/7460-1K**:

- ▶ **TOWER MUST BE MARKED** (painted), unless the tower is lighted with *high-intensity* flashing white lights (high-intensity strobes) or medium-intensity strobes.
- ▶ Towers up to 700 feet should have **seven (7)** evenly spaced bands; towers from 701 to 900 feet, **nine (9)** bands; towers from 901 to 1100 feet require **eleven (11)** bands and taller towers should be equipped with **thirteen (13)** bands.
- ▶ **The tower lighting and marking is the responsibility of the TOWER OWNER.** If the tower is shared, a written agreement can be made between the parties involved as to whose responsibility it is to monitor the lights and to decide when it must be painted.

One Tower, Two Photos



Non-Compliant Paint (FCC)



FCC-Compliant Paint Applied

Over the past twenty years non-painted towers incorporating white strobe systems have become increasingly popular. Their selling point is lower cost and less maintenance. One never needs to repaint an unpainted tower.

There are two serious flaws with this philosophy. Although strobe or LED lights may work well on cellular towers they have a tarnished record when placed in a high RF environment. Secondly, painting provides a duplex protection system for the tower steel. All modern towers are hot-dip galvanized to inhibit corrosion of the steel members. Galvanized coating can derogate and eventually allow steel to corrode. Paint acts as a second barrier and protects the galvanizing, in turn, offering extended protection for the steel. There are many advantages of using time-proven, incandescent red lighting systems and FAA painting schemes on future tower projects.

Three Basic Lighting Systems:

- 1) **Conventional Red Lights:** *Suitable for practically any tower height, but require painted markings.*
- 2) **Medium-Intensity Flashing White Obstruction Lights:** *Authorized on towers up to 500 feet AGL and will normally be at full intensity during daytime and twilight hours, then at reduced intensity during nighttime hours.*
- 3) **High-Intensity Flashing White Obstruction Lights:** *Operate at full intensity during daytime, reduced intensity at twilight and even less intensity at night.*

High-intensity strobes may be required for *non-painted* structures over 500 feet. In some instances, the FAA will permit dual lighting systems when medium or high-intensity strobes are used during day and twilight hours and conventional red lights are used at night. Paint is not required with this configuration, but this tower but is a much better neighbor at night. In many areas, zoning regulations require dual lighting unless the FAA absolutely insists on high-intensity strobes at all times. If this is the case, a station can count on complaints from the neighbors during nighttime hours!

Painted towers with red lights, *below left*, and Strobe system, *below right*.



Due to the high RF environments associated with TV and FM transmission, some prefer red lights and painted broadcast towers. Strobe systems are more costly to maintain and more susceptible to failure. Painted towers offer a dual protection system: the paint protects the galvanized coating which, in turn, protects the underlying steel.

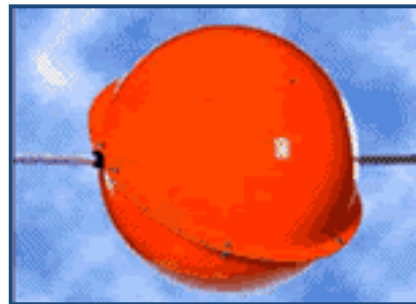
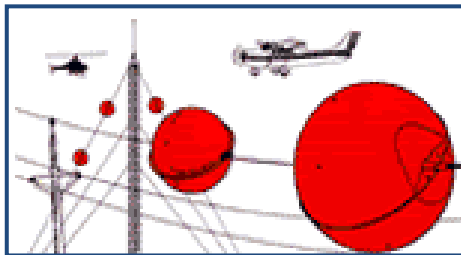
Proper maintenance and inspections are critical to ensure lighting systems are functioning properly and to capacity. The station's chief operator is responsible for insuring that all technical operations of the station are in compliance with the Commission's rules and regulations. Making certain the lighting system is on and working properly each day is part of this responsibility.

Annually, lighting systems should be closely inspected for signs of lightning damage, the #1 cause of damage to tower lighting systems. Additionally, check for signs of electrical arcing, defined as "an electrical breakdown of a gas which produces an ongoing plasma discharge, resulting from a current flowing through normally nonconductive media such as air". Arcing can also occur when a low resistance channel (foreign object, conductive dust or moisture) forms between places with different potential. Electric arc over the surface of plastics causes degradation.

The beacon should be unobstructed and not shielded by tower members or antenna appurtenances. The lens of the beacon must be inspected for clarity. A crazed lens results from minute cracking, hazing or the appearance of yellowing.

Grounding straps should be inspected for functionality. Mechanical and electrical attachments must be checked and deemed secure.

Aviation Balls are another viable safety measure used in collision avoidance, though they are not appropriate for use in all areas. While they *do* make towers and lines significantly more visible, the additional wind load created may outweigh the benefits.



If All Else.....

***DON'T SHOOT TILL YOU SEE THE WHITES OF
THEIR EYES!***

STAY WITH THE NATIONAL GUARD PSA'S!

The Remaining 10% of all Tower Failures is *Anchor Failure!*

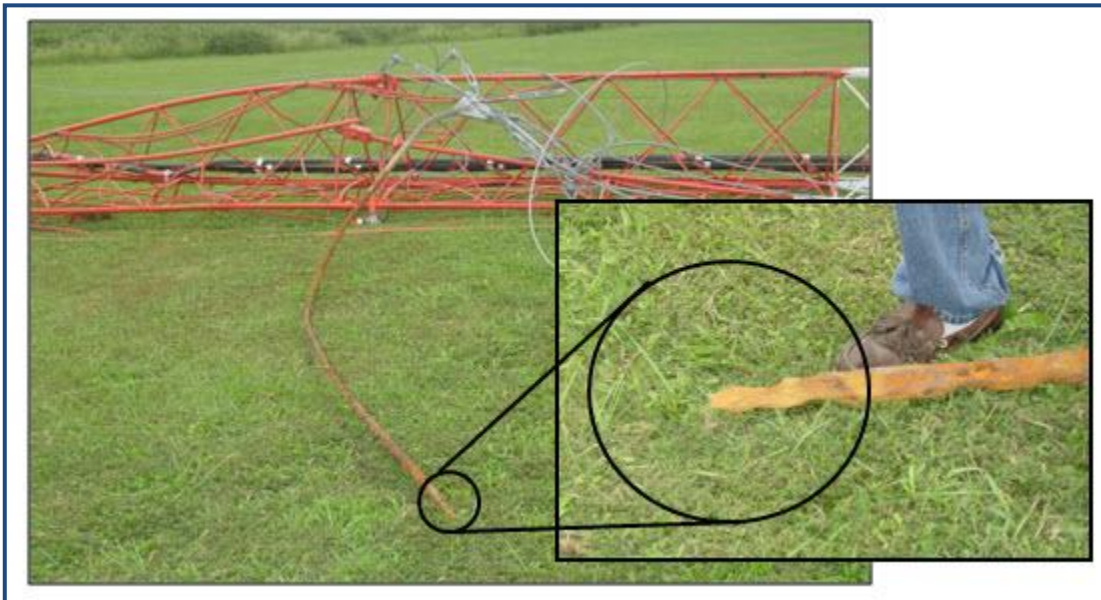
An earlier study conducted by *Stainless Tower, LLC* found anchor failure responsible for 5% of the broadcast tower failures. The **2010 CEI Study** provides concrete evidence that anchor failure is the reason **10% of all broadcast towers fail**. *We have seen a 100% increase in only 4 years!* What causes anchor failure? **Corrosion** of unprotected and buried steel members can cause anchor failure.



December 14, 2009, Tulsa, Oklahoma- “We are not totally sure why the tower fell,” said Chief Engineer Ed Bettinger. “This was a surprise. We just inspected the tower and tested the guy wire tension on April 20 and everything seemed fine.”

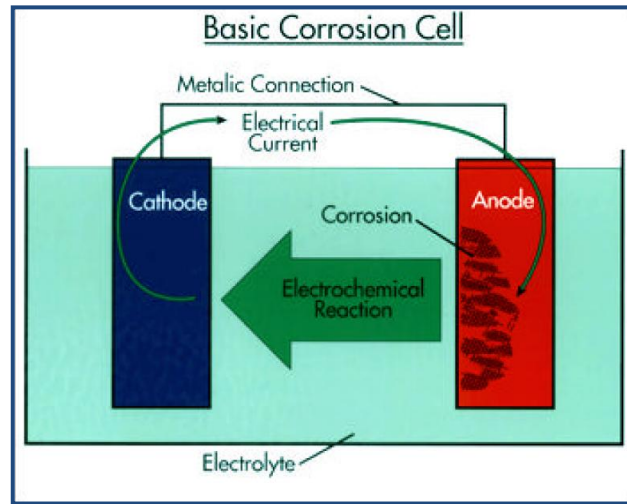
“We believe there was some electrolytic corrosion on one of the guy wire anchors several feet underground.” Bettinger said. “The high winds and the anchor letting go is probably what did it in.”

Corroded Anchor Rods, *shown below:*



Corrosion of an anchor shaft is the result of an *electrochemical process or galvanic action*, causing metal to deteriorate. *A galvanic cell requires five elements:*

- 1) **Anode**
- 2) **Cathode**
- 3) **Electrical Path (conductor)**
- 4) **Electrolyte**
- 5) **Current Flow**

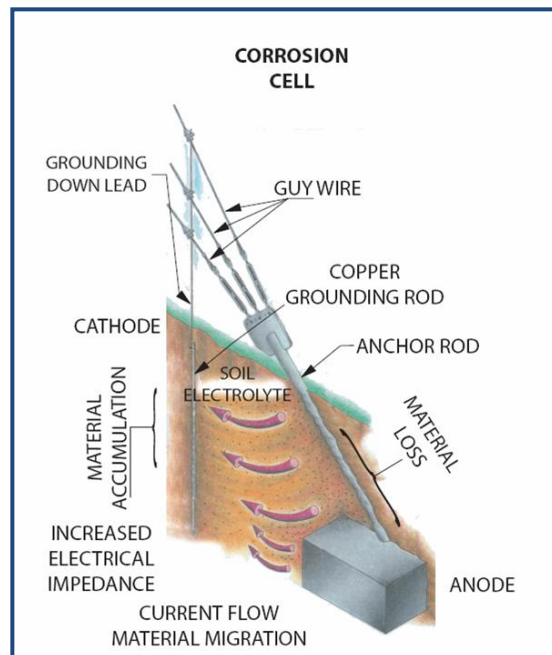


These five elements are present in both **External** (between metals) and **Internal** (same metal) corrosion.

Corrosion occurs when an electrical current is flowing from the anchor shaft to the surrounding soil. Material migration accompanies this current flow, with the more refined metals sacrificing to more noble metals. Galvanic corrosion occurs when there is a *self-generated* current resulting from an electrochemical reaction between *dissimilar metals*.

A guy tower anchor is a perfect example. The copper ground system is electrically connected to the galvanized steel anchor shaft through the guy wires. If the soil is conductive (low ground resistance) the difference in the electrical potential of the connected metals will create an electromotive force. The guy anchor shaft will sacrifice to the copper grounding system.

Anode (Most Active)	Magnesium
	Zinc
	Aluminum (2S)
	Cadmium
	Aluminum (175T)
	Steel or Iron
	Cast Iron
	Lead - Tin solder
	Lead
	Nickel
	Brass
	Copper
	Bronze
	Stainless Steel (304)
	Monel Metal
	Stainless Steel (316)
	Silver
	Graphite
Cathode (Least Active)	Gold



Electrolytic corrosion is similar to galvanic corrosion and occurs when the current source is external. Radiated or stray current captured by the guy wires or grounding system provide the electromotive force for electrolytic corrosion. However, the result is the same: deterioration of the steel anchor shaft.

EXTERNAL CORROSION Caused by *Dissimilar Metals* in Guy Tower Anchor



THREE SOURCES OF ELECTRICAL POTENTIAL

- 1. Galvanic corrosion caused by *dissimilar metals***
- 2. Galvanic corrosion potential caused by *dissimilar environments***
- 3. Electrolytic corrosion caused by *stray currents***



What about Hot-Dip Galvanization?

Hot-dip Galvanizing has proven to be ineffective for the prevention of galvanic corrosion. The main component of galvanizing is zinc. Zinc is very high in the galvanic series and acts as an anode with the coated steel acting as the cathode. When exposed to the atmosphere (CO₂), zinc forms its own *passivation film*. However, when buried in an anaerobic environment, the zinc sacrifices to the more noble metals, with an affinity for the copper grounding system.

SOIL CLASSIFICATION AND CORROSION

The 4 Elements or *Classifications* most contributory to corrosion are:

- 1) Particle size and aeration
- 2) Moisture content
- 3) pH (Hydrogen activity)
- 4) Chlorides and Organics

(#1) Soil Type	(#2) Particle Size	Corrosion Rate
Sand	.07 to 2 mm	Low
Silt	.005 to .07 mm	Moderate
Clay	less than .005 mm	High

PARTICLE SIZE

- **Low Corrosion Rate:** Coarse grain soil, less than 50% passing through a # 200 sieve
- **Higher Corrosion Rate:** Fine grain soil, more than 50% passing through a #200 sieve

MOISTURE CONTENT


Moisture content is typically represented in % moisture by soil weight, or the difference between in situ soil weight and dry soil weight. Generally, the greater the moisture content the greater the corrosion probability. Moisture content greater than 15% by weight would be considered *aggressive soil*.

HYDROGEN ION ACTIVITY (PH)

Extreme corrosion rates are to be expected in soils having either *low or high* pH. pH ranges from 0 to 14, with 7 considered neutral. A reading below 6 or above 12 should be considered *aggressive soil*. Soils comprising this list include cinder, ash, and slag fills, as well as organic fills, mine and industrial waste.

CHLORIDES AND ORGANICS (NATURALLY-OCCURRING CHEMICAL ELEMENTS)

Chloride concentration in the soil above 50 ppm is considered *aggressively corrosive* for steel. High levels are typically found in areas of historic salt water and may also be present where de-icing operations are prevalent.

<u>SOIL SYMBOL</u>	<u>SOIL TYPE</u>	<u>DEGREE OF RISK</u>	
PT	Peat and other highly organic soils	High Risk	
OH	Organic clay		
CH	Inorganic clay		
MH	Inorganic silts and very fine sands		
OL	Organic silts		
CL	Inorganic clays, silty clays, lean clays		
ML	Inorganic silts with fine sands		
SC	Clayey sands, sand-clay mixtures		
SM	Silty sands, sandy silts		Moderate Risk

Another simple method for classifying soil through visual observation is through color analysis. **Tan, red** or **light brown** colors indicate large particle, well-aerated soil. These sandy, lighter weight types of soil do not hold water for long periods. Soils of these colors have a lower probability of corrosion. In contrast, **gray** and **green/gray** soil indicates smaller particle size with poor aeration, bringing with it a higher incidence of corrosion. These types of soil are easy to identify because they are clumpy and clayey.

Cures for Anchor Rod Failure

Requesting a *professional*, on-site evaluation conducted by an engineering firm *specializing* in this field may be a worthwhile investment to determine your galvanic risk potential. I suggest contracting with a company such as ***CEI, an independent engineering consulting firm*** with the knowledge and resources to accurately inspect and detect active anchor rod corrosion.



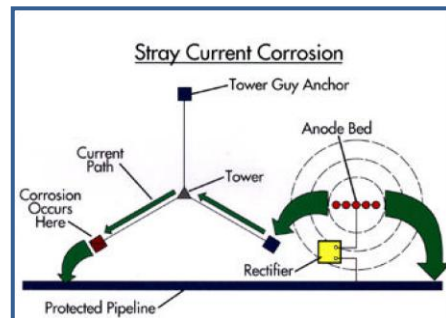
EVALUATE RISK POTENTIAL

- Evaluate risk-potential based on anchor environment
- Inspect shaft, depending on evaluation findings
- Install protective devices if active corrosion is indicated
- Replace anchor, if warranted

Inspect the exposed anchor shaft. If rust is visible it is likely corrosion is occurring at a greater rate further down the buried shaft.

Look for indications of an active, externally-driven anode bed and other sources of external electrical currents near the tower. The sources of these *stray currents* include:

- Plating works
- DC supply systems in industrial plants
- Large direct drive motors
- Welding Equipment
- DC communications
- AM tower site



Pipelines are a major concern when dealing with stray currents. The National Pipeline Mapping System (NPMS) is a valuable resource for locating pipelines. Their database can be accessed by visiting <http://www.npms.phmsa.dot.gov/PublicViewer/>

On-site Testing involves gathering information via electrical measurements. The data is interpreted and used to determine relative risk of galvanic corrosion on buried anchor shafts. **The three measurements taken during this type of on-site evaluation are:**

1. *Soil resistivity*
2. *Grounding system resistance*
3. *Electrical current flow on the anchor shaft*

Generally speaking, soils with a resistance less than 10,000 Ohm-cm would be considered *corrosive* and less than 5000 Ohm-cm *extremely corrosive*. A single 10' by 5/8" diameter grounding rod with a measured resistance of less than 16 Ohms would indicate a more aggressive soil. Additionally, direct current flow in excess of 15 mA detected on the anchor shaft would indicate an *aggressively corrosive condition*. Discharged current flow of 1 amp for one year will migrate 20 pounds of steel.

ANCHOR ROD INSPECTION

1. **Limited Excavation:** used by most installers to check for anchor corrosion before initiating any type of tower work. The soil around the anchor shaft is excavated to a twelve to thirty inch depth, revealing the shaft. If corrosion is observed, the shaft is completely excavated and inspected. At this point, decisions regarding the tower's stability are addressed.

If no corrosion is visible using Limited excavation at the 12" to 30" depth, an installer would conclude corrosion is not present at lower depths. This method lacks real value as it does not provide a true depiction of possible damage. The most common location for corrosion to manifest is at the intersection between the shaft and the buried concrete anchor block, not around the anchor shaft.



Limited excavation is not indicative of rod condition, *see photos above*

- 2. Total Excavation:** Involves removing the majority of the soil surrounding the anchor shaft and concrete anchor. While providing an unparalleled view of the anchor shaft, this invasive approach eliminates the majority of the anchor's uplift resistance. For safety and liability reasons, only experienced excavators are able to complete these inspections. This method can be cost-prohibitive, with the results are destructive and often tragic. The digging process could cause the sudden release of a compromised anchor shaft. Consequently, site limitations can render the anchor impossible to completely excavate.

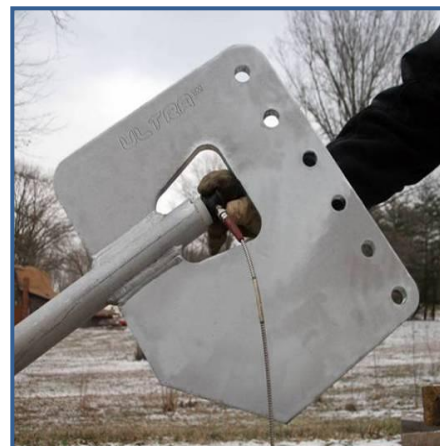


Drawbacks of Total Excavation:

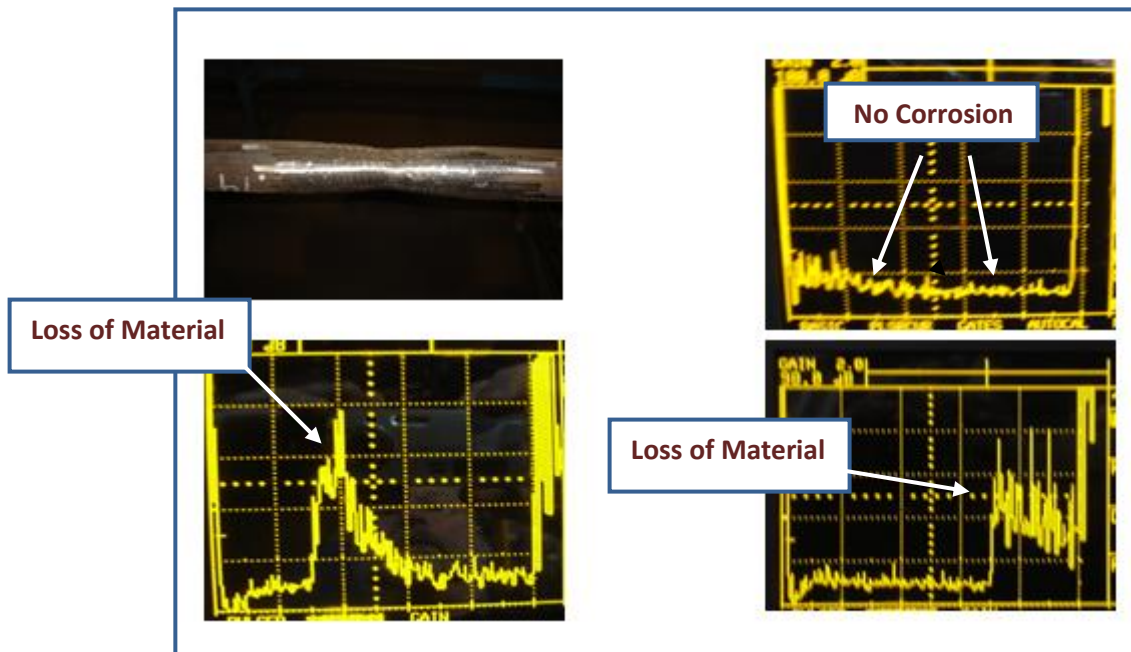
- *Expensive*
- *Destructive*
- *Dangerous*
- *Difficult to repeat*

- 3. Cylindrical Guided Wave-Ultrasound or Ultrasound:** The *most promising and effective* method for anchor shaft inspection. Most RF engineers are familiar with the process called TDR testing for transmission line. When using a TDR (time domain reflectometer), an electrical pulse is injected into a coaxial transmission line. This pulse is reflected if an anomaly is present in the line. Ultrasound testing works exactly the same with anchor shafts, except that the conductor is a solid round bar of steel and the pulse is sonic, not electrical.

Ultrasound testing is a practical means for interrogating anchor shafts from the surface, avoiding the problems associated with excavation. When properly administered, this method will locate and estimate the extent of corrosion damage and loss of steel material. Ultrasound testing is cost-effective and eliminates unnecessary destruction and liability concerns.



CEI Ultra™ Test Results



Ultrasound does have its limitations. This method is only effective with solid steel shapes such as a solid or flat bar. The anchor shaft and fan plate joint must afford access to the end of the shaft, allowing sufficient room to properly seat the UT transducer. Without adequate seating area, smaller, less sensitive transducers must be used, and the readings are typically less accurate. **Contact CEI to determine if Ultrasound testing is feasible for your site.**

CORROSION PREVENTION

If the electrical current of a corrosive cell can be disrupted it's possible to arrest the corrosion process. Typically, this can be achieved through the use of one or more of the following:

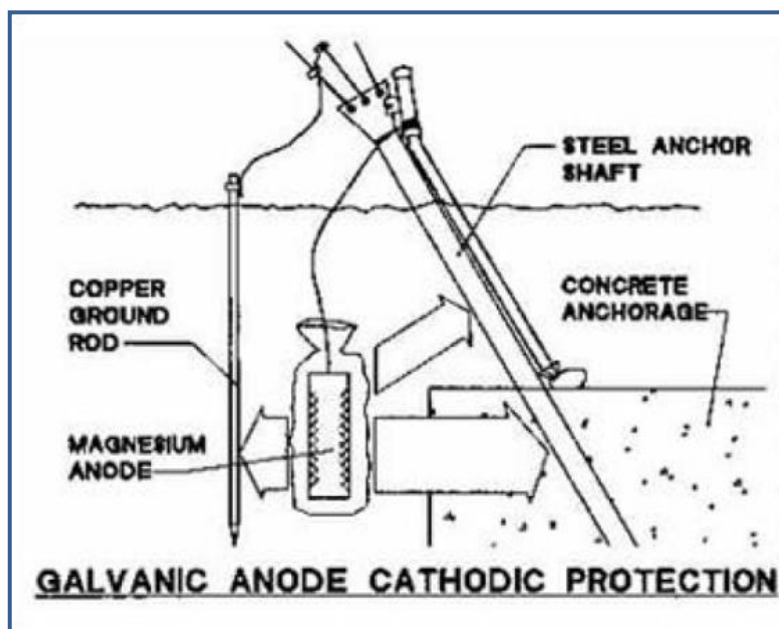
- *Concrete Encasement*
- *Coatings*
- *Impressed Counter Electrical Current*
- *Sacrificial Anodes*

Concrete Encasement is the traditional method used to lessen the possibility of galvanic corrosion of an anchor shaft. Until the early 1960, this was customarily included in major broadcast tower designs. Subsequently, with the propagation of FM and AM radio towers, concrete encasement during construction was widely discontinued as it became cost-prohibitive; Concrete encasement is expensive, costing as much or more than the supporting concrete dead-man anchor. Unfortunately, it cannot totally prevent corrosion. If insufficient reinforcing steel is incorporated in the design and the concrete becomes cracked, the effects of galvanic corrosion will not only be focused but intensified.

Coatings are a less expensive means of encasing an anchor shaft, as they are typically comprised of bituminous material or plastic tape. Both are fragile leaving them susceptible to damage during the transportation and/or installation process. Like a crack in concrete, if damaged, the effects of galvanic corrosion will be localized and intensified. Coatings are also difficult to apply in the field.

Impressed Counter Electrical Currents can be artificially induced within the tower structure opposing the polarity of the naturally accruing electrical currents of the galvanic cell. Although this method has proven very successful in protecting structures such as underground pipe lines, it is not practical for use with most guyed towers. In addition to costly installation, this method requires constant monitoring and adjusting to keep the counter current balanced and the galvanic cell current balanced. Over-protection can lead to galvanic corrosion and may also hasten corrosion in non-protected structures.

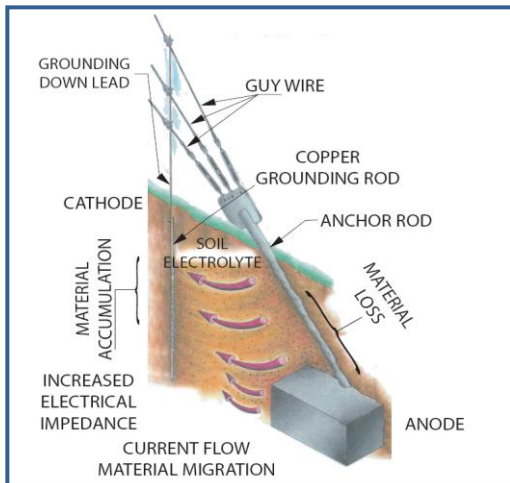
Sacrificial Anodes offer the most effective protection. With a sacrificial anode, the base metal is much higher in the galvanic series than steel. Translated, if the soil is sufficiently conductive, the anode sacrifices to the anchor shaft preventing its corrosion.



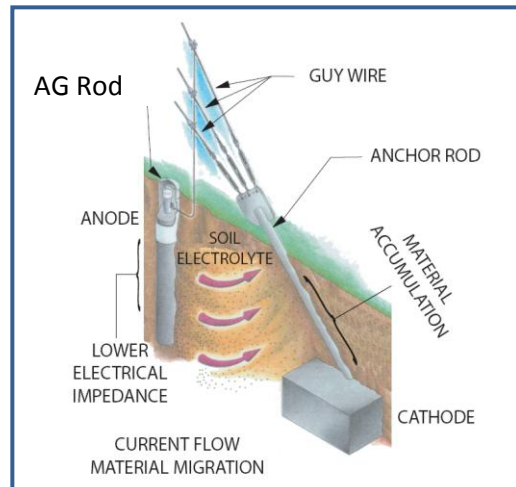
Unfortunately, sacrificial anodes may simultaneously *reduce* the effectiveness of the tower grounding system via the transference of insulating material directly to the grounding electrode. The photo, *right*, displays a grounding rod originally connected to a tower guying system which employed a sacrificial anode. Notice the isolative "coral-like" material coating the grounding rod. Increased resistance in the anchor grounding system increases the likelihood of damage to the anchor as a result of a lightning strike.



The AG Rod™ is a viable option for avoiding the problems associated with most sacrificial anodes through combining the sacrificial anode and the grounding system. The **AG Rod™** is a chemical grounding rod offering very low electrical resistance for fault currents. This accessory is comprised of a magnesium alloy which is significantly higher in the galvanic series than steel. The benefit is seen when the soil becomes sufficiently conductive. The **AG Rod™** sacrifices to the anchor shaft, preventing corrosion. Furthermore, electrical resistance of the **AG Rod™** decreases over time, as opposed an increase in electrical resistance using a standard copper base grounding rod equipped with a separate sacrificial anode



Corrosion Cell



AG Rod™ Protected

With information and knowledge concerning galvanic corrosion becoming more commonplace for those in our industry, requests for *CEI's non-invasive and cost-effective* Ultrasound anchor rods testing are on the rise. This '*specialty*' inspection method is gaining popularity as an extremely effective tool for detecting anchor rod corrosion determining the next step(s) in saving a structure.

SUMMARY

THE MORAL OF THE STORY

Had the guidelines and recommendations contained in this report been implemented, wholly or in part, up to 70% of the failures referenced for this study *would not* have failed.

To expect tower owners and/or station engineers to be adept and knowledgeable about every intricacy and detail of broadcast tower design, fabrication and maintenance may be unreasonable. Many tower designers and fabricators (and engineers) lack proper training and, at times, fail to heed appropriate protocol. Hence, my goal of compiling this data in document form is that you have gained a firm understanding of the need to become familiar with the Standards and protocols set forth to protect you *and* your investment, and insure you're receiving exactly what your needs require, without a doubt. I'm certain you will now applaud the benefits of formulating detailed specifications *prior* to embarking on any new tower-related venture.

This document isn't intended to serve as a 'manual', but to illustrate the need for continued education and guidance, with respect to commonly over-looked details.

In the grand scheme of things, hiring competent professionals to guide you will prove relatively inexpensive compared to the economic consequences of catastrophe. Appropriate Standards and Specifications are just a starting point for ensuring a properly designed, fabricated, installed and maintained product. Are you confident you've received exactly what you've ordered? Here's *my* analogy:

LOOK INSIDE THE BAG!



Recall how many times have you placed an order *to-go*, only to get home and find what's in the bag is *not* what you ordered *and* paid for? Though we're talking towers, not burgers, the concept still applies.

YOUR ORDER:



Big Mac Extra Value Meal®

YOUR DINNER:



Kid's Meal

OR

Verify the requested and required specifications are included in the design, installation, and maintenance of your tower. Don't hesitate to look inside the bag, or ask for help **BEFORE** you place your order and while it's being '*prepared*'.

CONSOLIDATED ENGINEERING (CEI) has devoted a professional lifetime to insure our client's tower(s) and related construction tasks not only fit their needs, but are specifically tailored, properly ordered and economically feasible. Our success in the past is your future **guarantee** when using **CEI**.



Dave Davies

CEI Consolidated Engineering Incorporated

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