RP 401

FOUNDATION INSPECTIONS, MAINTENANCE AND BASE BOLT TENSIONING PROCEDURES

PREFACE

The following Recommended Practice is subject to the Disclaimer at the front of AWEA's Recommended Practices Manual. It is important that users read the Disclaimer before considering adoption of any portion of this Recommended Practice.

SAFETY NOTICE

These process guides are not intended to assure safety, security, health, or environmental protection in all circumstances. Implementers of the processes are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

PURPOSE AND SCOPE

This set of recommended practices addresses the common maintenance issues related to foundation inspections, maintenance and base bolt tensioning procedures. It is not machine specific and some adaptation may be required based on specific designs.

INTRODUCTION

The operation of a wind turbine generator and the resulting stresses to the foundation make routine inspections and testing essential to maintaining the structural integrity of the turbine. The recommended practices for foundation maintenance contained in this section pertain to inverted T spread footings with a peripheral arrangement of anchor bolts holding the tower to the foundation in tension. It should be noted that the vast majority of turbine foundations in North America are this type. For turbines supported by different foundations, similar inspection and

maintenance procedures can be implemented with some alterations depending on the circumstances.

1. DEFINITIONS AND DIAGRAMS

1.1. Anchor Bolt

The steel stud which attaches the tower base to the foundation.

1.2. Anchor Nut/Hex Nut

The Anchor Nut holds the tension load of the anchor bolt to the tower base flange.

1.3. Kip

A unit of force that equals 1,000 pounds.

1.4. PSI

A unit of force equal to 1 pound per square inch.

1.5. Diagram of bolts/tower wall. *(See Figure A.)*

1.6. Anchor Bolt Numbering Example Diagram. *(See Figure B.)*

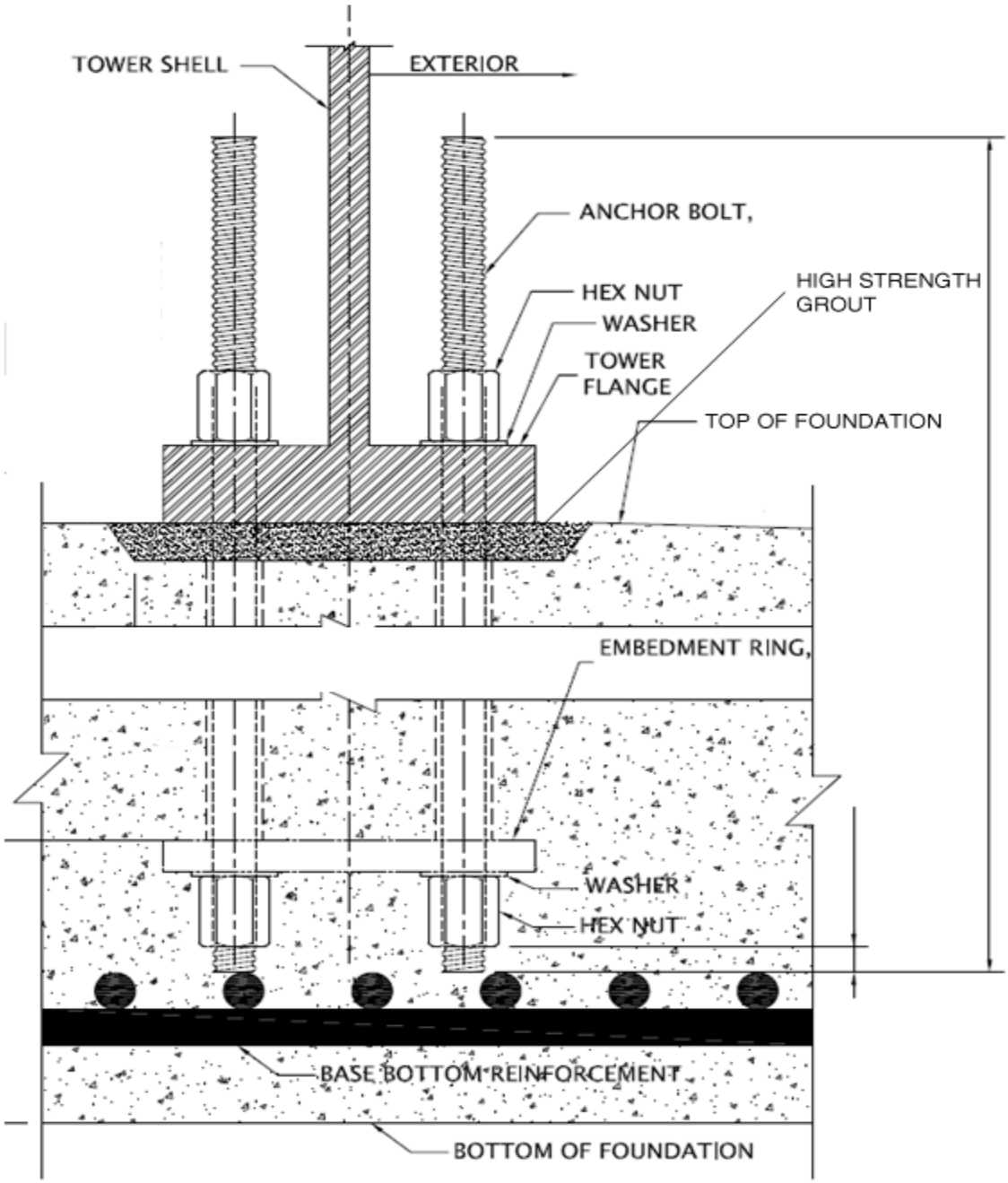
TOWER SHELL
EXTERIOR
ANCHOR BOLT,
HEX NUT
WASHER
TOWER FLANGE
HIGH STRENGTH GROUT
TOP OF FOUNDATION
EMBEDMENT RING,
WASHER
HEX NUT
BASE BOTTOM REINFORCEMENT
BOTTOM OF FOUNDATION

Figure A.

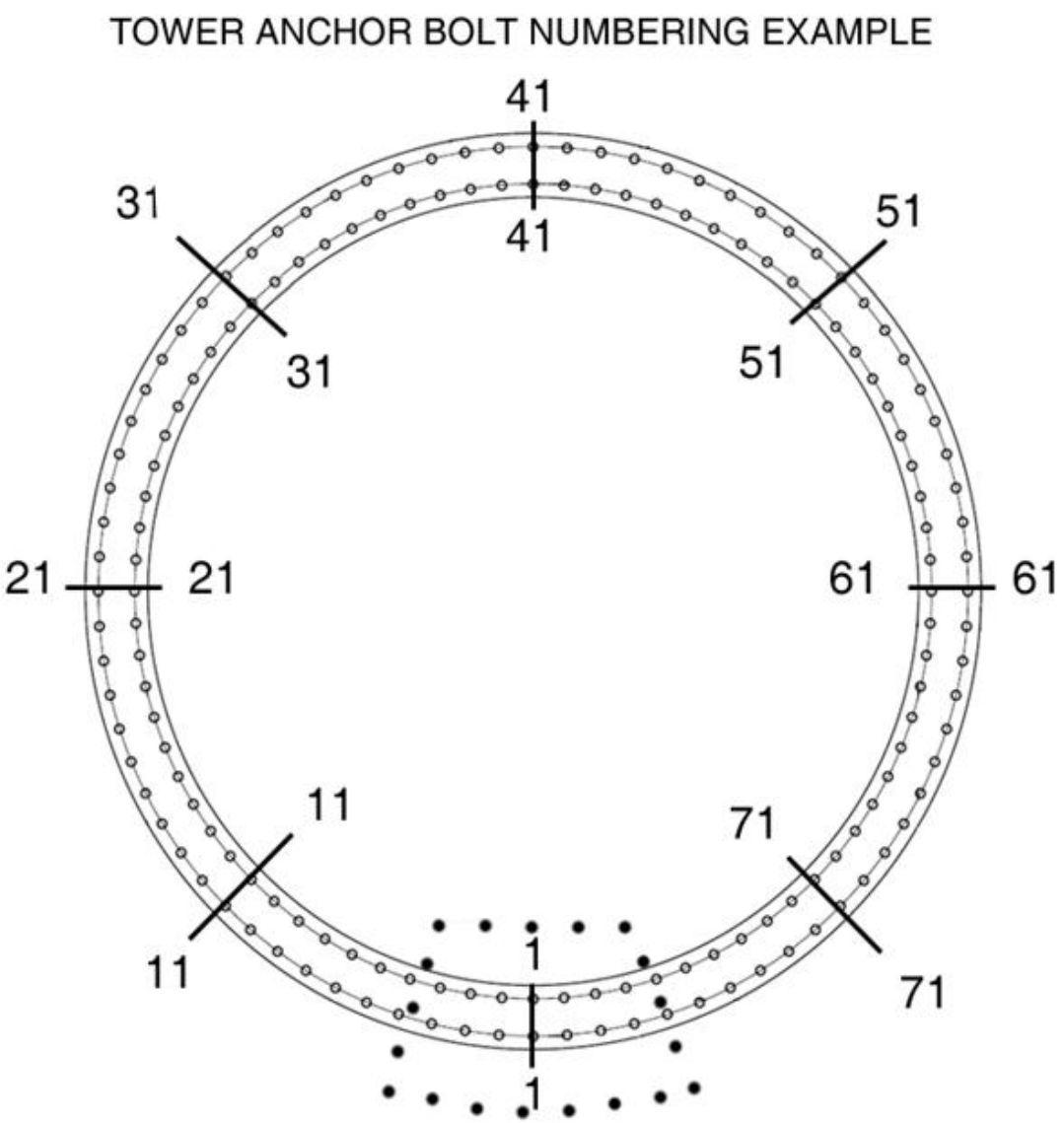

Figure B.

2. SAFETY

2.1. Personal Protective Equipment (PPE) must always be worn while performing tensioning work. This includes but is not limited to hard hats, shatter-proof safety glasses, EH protected steel-toed work boots, leather gloves and non-melting work clothing.

2.2. Equipment and tooling inspections should be performed before every shift. Run maximum daily pressure through tensioning system in controlled environment to check for leaks. Replace faulty components immediately if leaks are detected. Hydraulic oil injection into bloodstream is a major health and safety concern.

2.3. Follow OSHA guidelines for inspecting and marking all power tools, cords, ladders, etc.

2.4. If working conditions are classified as a confined space, all necessary measures must be followed to ensure a safe and proper work environment.

3. INSPECTIONS

3.1. 10% anchor bolt tension inspections

10% anchor bolt tension inspections are to be performed once a year for years 1-5 and every 5 years thereafter if all bolts pass final inspection. See section 6: *10% Tensioning Procedures* for full description of procedure.

3.2. Grout and concrete inspections

Grout and concrete inspections are to be performed yearly on 100% of the turbines for the first 5 years of the project. After the 5 year benchmark, 50% of the turbines should be inspected yearly for the remainder of the project. If issues are discovered on any turbines during the inspections, 100% of the turbines should be inspected at that time. If cracking or spalling is discovered, it must be tracked and documented. If repairs are necessary, perform them immediately or they will likely worsen. If inspections reveal cracking or spalling of the concrete or grout, seal them immediately with an approved sealant. Monitor and document every 4 months from then on to ensure issues do not worsen.

3.3. Anchor bolt corrosion inspections

Anchor bolt corrosion inspections should be performed in conjunction with grout and concrete inspections. Inspect for corrosion of interior and exterior anchor bolts, nuts and washers. If corrosion is present, note and rectify immediately with approved greases or anti-corrosive coatings. **Treat corrosion as a foundation indicator.** If anchor bolts are excessively corroded there is a high likelihood the nuts are seized to the bolt, and the bolts are not holding proper tension.

3.4. Complete approved inspection documents for each turbine. These documents must reflect all relevant findings and data. Being able to reference historical documents can become an invaluable tool as the project ages.

4. EQUIPMENT

4.1. Tensioning system calibrations are to be verified 3 times daily when performing 10% tests and before every tower on 100% tensioning. As ambient temperatures rise and fall, it is likely that the temperatures of the hydraulic oil will change as well, possibly resulting in varying PSI's of oil pressure needed to achieve the desired load. All calibrating machinery, including oil gauges, must have current certifications. If variations of more than 5% are detected during calibrations throughout the day, the previous tower completed should have 4 bolts tested at random to ensure they have been tensioned properly. If tests reveal loose anchor bolts, rectify as necessary.

4.2. Maintain pumps, jacks and hoses in controlled environment. Never store in freezing temperatures.

4.3. Keep working pumps in controlled environment if ambient temperatures are below freezing. A heated van, box truck or heated trailer all work fine for maintaining acceptable working temperatures of the pumps.

4.4. An oil pressure regulator should be utilized on the pump to assure that the desired PSI is being achieved each and every throw. Many pumps available today will push 20,000 PSI in as little as 3 seconds. At these speeds, discrepancies by the pump operator in fractions of seconds will result in thousands of pounds of differing tension. Setting the pressure regulator to a desired PSI, verified by the tensioning calibrator is the only way to ensure the proper tension is applied to each anchor bolt every time.

4.5. The tensioning system must allow for visibility of the anchor nut and washer on the bolt being tensioned. Being able to observe the nut and washer lifting under tension, and then being able to visually confirm that the nut has been properly tightened under tension is of utmost importance. Often times on operational projects nuts and washers corrode to each other and to the anchor bolt, thus requiring force to break them free. If anchor nuts are found to be sticky, two pancake jacks with a steel plate will allow for the throw of a large wrench. If nuts are moving freely, a single over-the-bolt tensioner will work fine, but it must allow for visibility of hardware for the reasons stated above. If the anchor nut and washer are not tight to the tower flange prior to releasing pressure from

the tensioning system, the anchor bolt is not properly tensioned. Appropriate testing will reveal such issues.

5. 10% TENSIONING PROCEDURE

5.1. Approximately 1 year after the project has been 100% tensioned, 10% of the anchor bolts should be selected at random on 20% of the turbines. The testing value should be to the lowest specified engineered value. For example if the foundation drawings specify a tension of 75kips +5 -0 then all 10% testing is to be done at 75kips.

5.2. Anchor bolts should be numbered beginning with the bolt centered under the tower door being number 1 *(see Figure B)* with subsequent numbers in ascending order clockwise around the circumferences of the interior and exterior base flanges. The referenced bolt numbers should fall in the same position on every tower of the project.

5.3. Two exterior/interior anchor bolts will be selected at random as a starting point. From the starting point, tension every 10th bolt until a minimum of 10% of the bolts have been tested.

5.4. Every bolt tested must have visual confirmation from technicians that the anchor nut is tight to the flange prior to releasing tension from jack(s). If nuts are sticky from corrosion, necessary means must be employed to ensure the anchor nuts are tight to base flange prior to releasing pressure from the tensioning system.

5.5. Through performance documenting (outlined below) determine if the tower has passed or failed the tensioning check. If any singular anchor bolt is discovered to have an “as found” tension of less than 85% of the specified tension, it is to be deemed a failure and will require 100% of the anchor bolts to be tensioned on that tower following the procedure described in section 7.

5.6. If the population of tested anchor bolts has an average “as found” tension of less than 90% of the engineered specified value, that tower is to be deemed a failure, thus requiring 100% re-tensioning.

5.7. If any of the foundations fail the 10% test, then all of the foundations on the project must be 10% tested.

5.8. Repeat 10% tension check procedure as stated above on years 2 through 5 of the project. After year 5, when all of the foundations have been tested, and foundations have been properly tracked, revert to a 10% tension check on 20% of the project every 5 years for the remainder of the project, following the same pass/fail criteria. A different 20% of the foundations should be tested every year, so at year 5, all foundations will have been tested and documented.

5.9. Technician should sign interior tower basement wall under the doorway with initials, date and description of work; i.e. 10% tension @ 75 kips, and company abbreviations.

5.10. Sample 10% tension testing report. *(See Figure C.)*

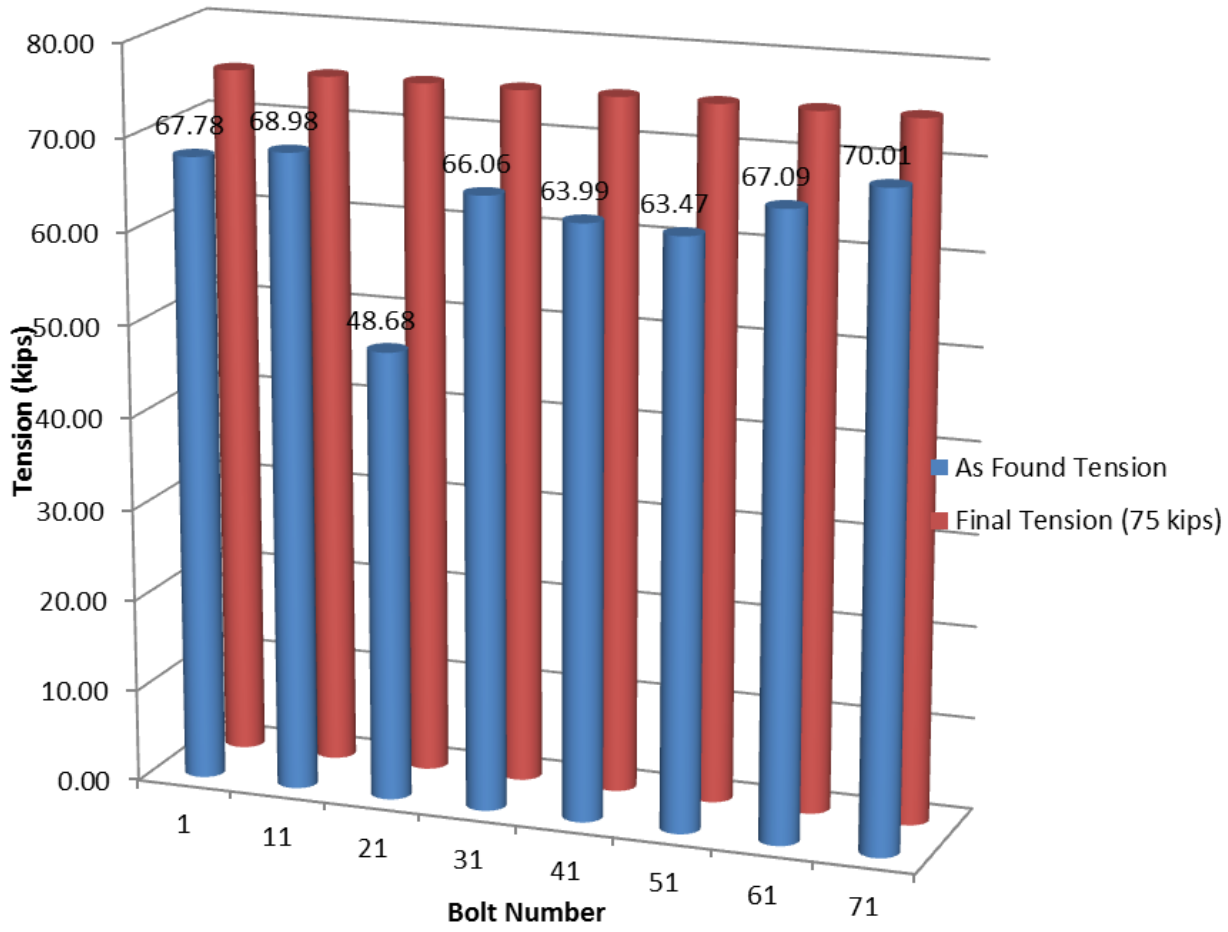

Figure C. As Found Tension (kips) vs. Final Tension (kips).

6. 100% TOWER TENSIONING

6.1. After construction has achieved final completion, a 100% anchor bolt tensioning should be completed within 6 months. It is important to record and document tension findings during this time.

6.2. Number foundation anchor bolts with permanent paint pen on top of bolt. Follow numbering sequence outlined in section 6.2 and illustrated by Figure B. *(See Figure B.)*

6.3. 100% tensioning should be completed to the highest engineered specified value. For example, if the foundation drawings specify a tension of 75kips +5, -0 then the 100% tensioning value is to be completed at 80kips. Verify proper system calibration every tower.

6.4. Beginning at bolt 1, tension all anchor bolts in ascending numerical order around circumference of tower to desired tension.

6.5. Repeat immediately on opposing flange.

6.6. Technicians should sign interior tower basement wall under doorway with their initials, date, description of work, i.e. 100% tension @ 80kips, and company abbreviations.

6.7. Accurately record and report findings for each anchor bolt tensioned. This condition monitoring information will be utilized for future evaluations of 10% checks, and offer historical data for monitoring performance and identifying future failures before they happen. Anchor bolts that continually lose tension are indications of larger issues that include but are not limited to grout failures, foundation failures, foundation settling, concrete shrinkage, chronic anchor bolt relaxation, poor previous workmanship, etc.

SUMMARY

The forces that wind turbines endure from harnessing the wind causes continual strain to their foundations. Construction builds a stationary structure; operations maintain the working structures. As the wind industry matures there is a growing understanding of the importance to properly maintaining the foundations. The earlier an owner can start monitoring a foundation's performance, the higher the likelihood of identifying warranty issues now, and preventing costly issues later.

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