



3/7/17

Ms. Maria Pandazi
City Planner
City of Waukesha – Department of Community Development
201 Delafield St.
Waukesha, WI 53188

Re: Structural Evaluation of 100' Monopine Tower
Waukesha Airport II, WI
Site Number 784719
LEI Project No: 31170053.000

Dear Ms. Pandazi,

As requested, I have evaluated the letter, drawings and calculations for their structural content, that were submitted to the City of Waukesha by US Cellular which are dated January 23, 2016.

The findings are as follows:

Splice at 80 feet from base and the fall radius.

Splice at 80' is an end plate type connection with (10) - 7/8" diameter A325 bolts. See Figure 1. The splice is the point at which failure would first occur under the wind load according to the calculations submitted. Its capacity vs. load is shown as 96.2 % of unity.

Unity is the percent of the design strength that is being used by the load, 100% would mean that all of the design strength is being used by the load applied. Less than 100% is acceptable as there is more resistance capacity than load, greater than 100% is not in compliance with the code, and it is using more of the resistance capacity than allowed by code. The design load is the load at which the structure would fail in some fashion divided by a safety factor that is code prescribed. So, when a structure is at 100% unity it is not at failure load, but at the maximum load it can be at and still have the prescribed code required safety factor.

The monopole itself is at a much lower unity ratio, and therefore it appears from the calculations submitted that the weak link in the entire structure is the splice at 80'. If the splice is loaded to its failure load the rest of the structure would not be at failure load. There are two critical conditions where the splice may fail. If the pole is bending about the A-A axis as shown in Figure 1, or if the pole is bending about the B-B axis as shown in Figure 2.

Refer to Figure 1. Based on the A-A axis bending direction, bolt #1 would fail first. Once bolt #1 fails, bolts 2 and 3 quickly overload and fail. This effect cascades to all the other bolts in rapid

succession causing the entire splice to fail. This would lead to a separation of the upper pole from the lower pole at 80 feet.

Based on the B-B axis bending direction, bolts 1 and 2 would fail at the same time. Bolts 3 and 4 would instantaneously after that, causing the entire top part of the tower to separate from the lower portion.

Once the upper portion has separated from the lower portion, the upper tower will fall taking 2.23 seconds to hit the ground. During that 2.23 seconds the upper tower will go from an initial horizontal velocity of zero feet/second to 19.9 feet/second horizontal velocity at impact due to a constant wind loading pushing the portion of the tower away from lower portion. The distance traveled which is predicted by this increase in horizontal velocity is 30 feet under the failure loading. Once the tower hits the ground, I am assuming that it will fall in the direction of travel and the total distance from the center of the remaining tower to the tip of the dislodged tower portion is 44 feet. Note that this scenario does not include the impact of the upper tower tumbling end over end, which would increase the distance that it could travel by increasing the area exposed to the wind.

Therefore the fall radius is a minimum of 44 feet with failure level wind loads.

The letter dated January 23, 2017 by US Cellular stating that pole will fold over onto the portion below is not accurate. If the critical failure mode predicted by the calculations is the tensile failure of the bolts in the splice at 80 feet, the pole will not fold over as stated, but separate and fall as described above. The letter claims that the "Monopine will yield at the location of the highest combined stress ratio within the flanged connection.", but the failure mechanism of a A325 bolt exceeding its tensile capacity is a sudden fracture limit state as indicated by the phi factor used of .75 for these types of bolts by AISC (American Institute of Steel Construction). If these bolts failed in yielding the phi factor used by the code would be .9 as in other tensile members.

Note that a phi factor is also known as a resistance factor and vary based on the type of member and limit state being considered They add to the overall safety factor of the structure..

Foundation required cover

See Figure 3. The foundation for this tower is a 23 foot x 23 foot concrete pad buried 4' - 6" below grade. Referring to figure 3 which is part of the C-5 drawing supplied by US Cellular. The cover indicated by the drawings is not sufficient to satisfy the design in the calculations. There is a note on the C-5 drawing upper right-hand corner that anticipates this happening. Therefore the grading plan would need to be changed to satisfy the calculations given.

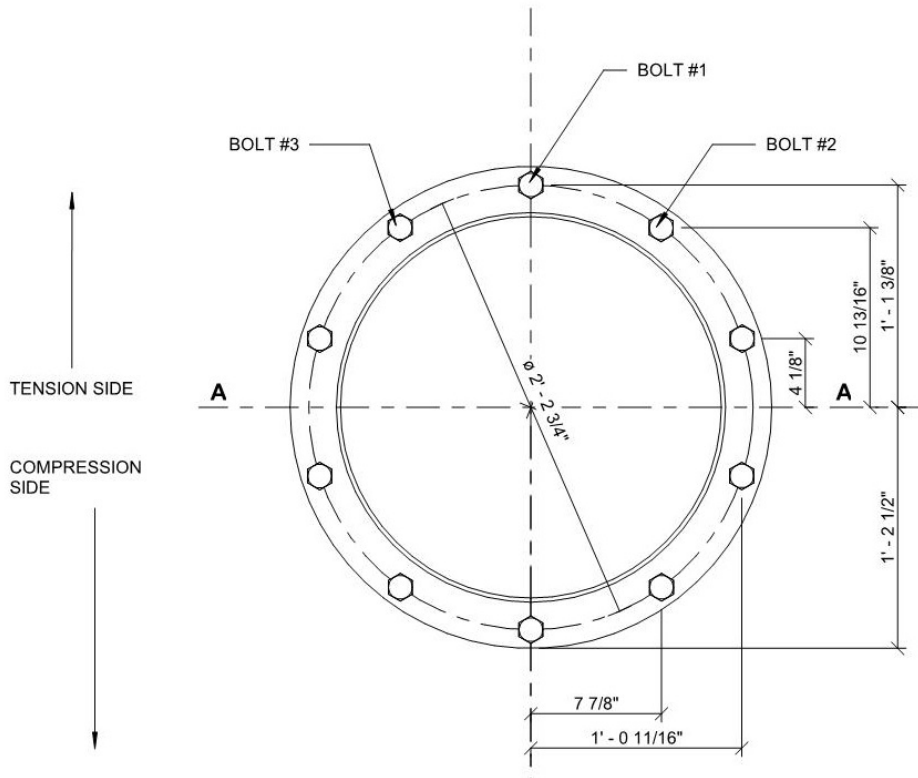


Figure 1. Splice Configuration at 80 Feet.

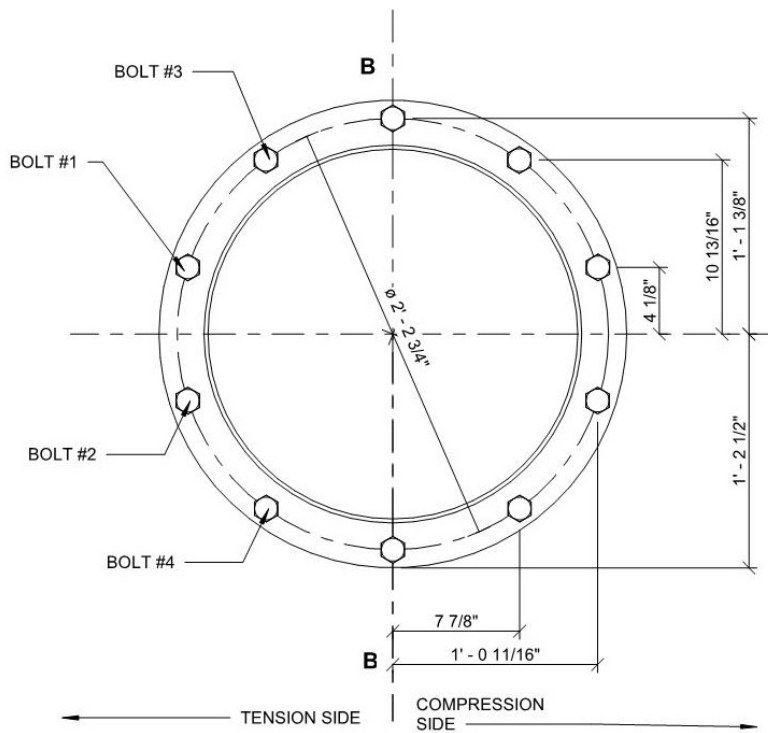


Figure 2. Splice Configuration at 80 Feet.

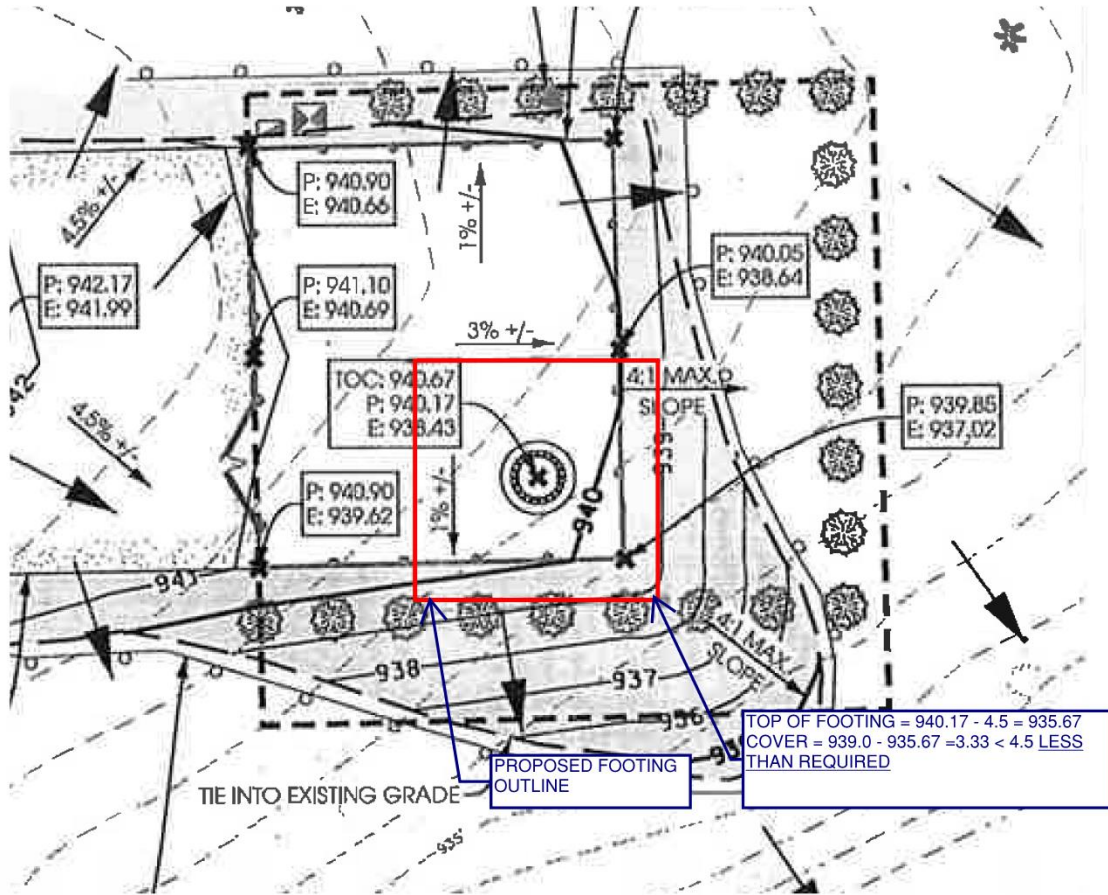


Figure 3. Site Plan per C-5

If the manufacturer has test data that shows a different failure mode we would be happy to review it, however it does seem as if the brittle bolt failure is the weak link in this pole design.

Please feel free to contact our office if you have any questions regarding this letter. We appreciate this opportunity to be of service to you and thank you for selecting Larson Engineering, Inc.

Sincerely,
Larson Engineering, Inc.

James A. Lijewski
 James A. Lijewski, P.E., S.E.
 Senior Structural Engineer

