21 July 2022

Mr. Raul Velez
Vice President & Chief Operating Officer
Sutro Tower, Inc.
1 La Avanzada Street
San Francisco, CA 94131

Project 067199.24 – Sutro Tower, Cladding Options Assessment

Dear Raul:

This letter supplements my letter to you of 28 June 2022 on the same subject. Specifically, it responds to San Francisco Planning Department's requests that we clarify the impracticality of replacing the cladding on the Tower's legs, in the original configuration, and also meet the structural requirements for new essential structures under the present San Francisco Building Code (SFBC).

1. SUMMARY

In summary, in light of the agreement in place with the neighbors to voluntarily upgrade the Tower in compliance with current building codes as codified as a condition of approval of the repack permit, I, along with a group of city-appointed peer reviewers, concluded that the Tower can meet those requirements, as designed, with the permanent removal of the vertical, architectural, cladding panels. In 2019, the Department of Building Inspection issued a permit for voluntary structural upgrade of the Tower to bring it into compliance with the 2016 SFBC requirements for new essential buildings, assuming cladding on the legs removed.

The alternative of replacing the cladding in the triangular configuration which existed prior to the temporary removal is not compliant with Tower ownership's commitments. Cladding elimination is the best option, structurally, for the Tower, and has a byproduct of improving overall safety for those working on Sutro Tower and those recreating and living nearby.

2. BACKGROUND

Sutro Tower was originally developed in the early 1970s, under the 1956 SFBC, as amended in October 1972. Under that code, the structural design of the Tower was required to consider wind loads that varied from 15 psf at the Tower's base to 35 psf at its top. Tower design also complied with the requirements of the Electronic Industry Association Code RS222A-1966. The Electronic Industry Association Code required the design for a uniform wind load of 50 psf, substantially more than required by the SFBC of the time.

In the 1990s, as part of proceedings associated with obtaining a building permit to convert the Tower from analog to digital transmission, Sutro Tower Inc. (STI) entered into an agreement under which STI was required to upgrade the Tower to comply with the structural requirements of the then-present SFBC, as applied to new essential facilities. Under the terms of such conditions, STI upgraded the Tower for wind and seismic resistance in the 1990s, in the first phase of the digital conversion. In 2003, STI conducted a second phase of the digital conversion. SFBC requirements for wind had not changed at that time, but seismic requirements had, and STI again upgraded the Tower for seismic resistance.

In 2016, STI initiated a project to modify the Tower to accommodate the Federal Communications Commission (FCC) mandated repacking of broadcast frequencies. The repack project required the replacement of the major broadcast antennas, including one of the three masts atop the Tower in its entirety. Under the agreement with the city and the neighbors as incorporated into a condition of approval for such repack project, STI was required to perform a structural upgrade to conform to the requirements of the 2016 edition of the SFBC as applied to new essential structures. Our conclusions which are described in more detail below were presented to the Planning Department, the Department of Building Inspection and the Tower's neighbors in 2017-2018.

In the time since the digital television conversion projects (2003), San Francisco, like other California cities, had adopted an entirely new building code based on the International Building Code and its adoption of the ASCE 7 Standard for Minimum Design Loads for Buildings and Other Structures. The seismic requirements of this newer code were similar to those in place in 2003. However, the wind loading requirements were substantially more severe. Rather than design for winds with a 50-year return period, as required by earlier codes, the updated SFBC requires the design of new essential structures for winds with a 3,000-year return period. Wind pressures under the new code range from 75 psf at the Tower's base to 90 psf at the top. For reference, this is a 50% increase in wind loading at the tower base and a near doubling of wind load at the top, compared to that for which the Tower was originally designed, which was already near double that required by the then current SFBC.

It should be noted that because the city adopts a new building code every three years, and because each new code changes some requirements compared to those of the earlier edition, nearly every building and structure in the city is noncompliant with the provisions of the current code for new buildings and structures in some ways. The SFBC recognizes that it is impractical to require an upgrade of all existing structures when the city adopts a new code and identifies specific circumstances that trigger a requirement to upgrade structures into compliance. These triggers relate to substantive addition, alteration, or repair of the structure. The Department of Building Inspection has ruled that under the terms of the SFBC, the alterations made as part of the repack project are not sufficient to trigger a structural upgrade. Therefore, except as required by the condition of approval and related agreement with the neighbors, there is no code mandate to perform a structural upgrade of the Tower and the Tower could be considered, even if clad in its original configuration, to be compliant with the requirements of the present SFBC as applied to existing structures.

3. STRUCTURE DESCRIPTION

Sutro Tower is a 977-foot tall, free-standing, steel structure. Figure 1 is an isometric view of a model of the Tower structure, illustrating its principal components.

The Tower includes three essentially vertical elements, called legs, and labeled “A”, “B,” and “C” in the isometric. The legs are arranged in plan at the corners of an isosceles triangle and are joined by five horizontal levels, labeled Level 2 through Level 6. At the Tower’s base, the legs are 150 ft apart along each side of the triangle. The legs slope from the vertical such that at Level 4, the legs are 60 ft apart and at Level 6, 100 ft apart. A series of diagonal cables are arranged in an “X” pattern between the legs and horizontal levels, along each face of the Tower’s faces.

Each of the three legs is in the form of a truncated isosceles triangle, with a side dimension of 7 ft, and as illustrated in Figure 2, is formed by: two major columns and one minor column. The columns are interconnected on each face of the triangle by a series of diagonal “⅂ Г”-shaped steel braces and also by a series of horizontal cladding supports. Each of the three columns is a 14-inch-deep wide flange structural section. At the Tower’s base, major columns have a weight of 500 pounds per foot of length and minor columns 150 pounds per foot of length. The braces and cladding supports act together to tie the three independent columns together so that each leg acts as an integral structural member. Figure 3 shows a partial elevation of the Tower, at a location where two legs intersect with horizontal Level 3 and illustrates the configuration of the individual columns, braces and cladding supports.

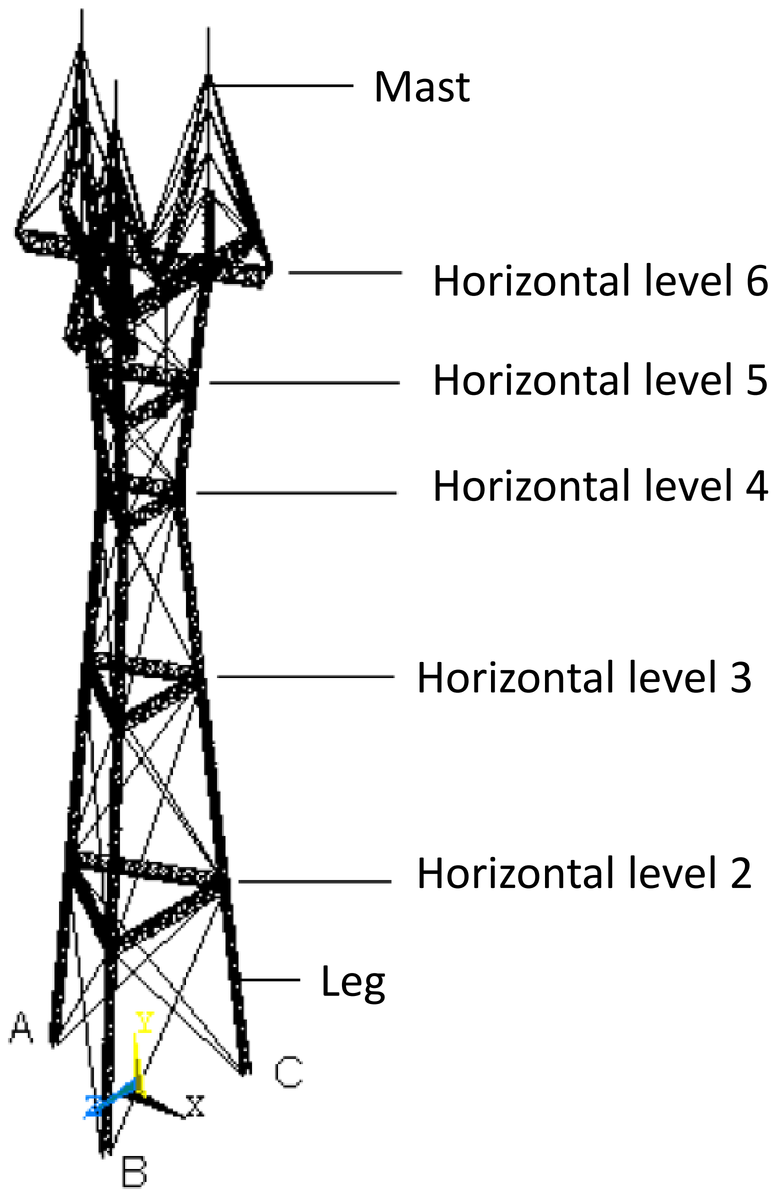

Figure 1 – Isometric of Sutro Tower Structure

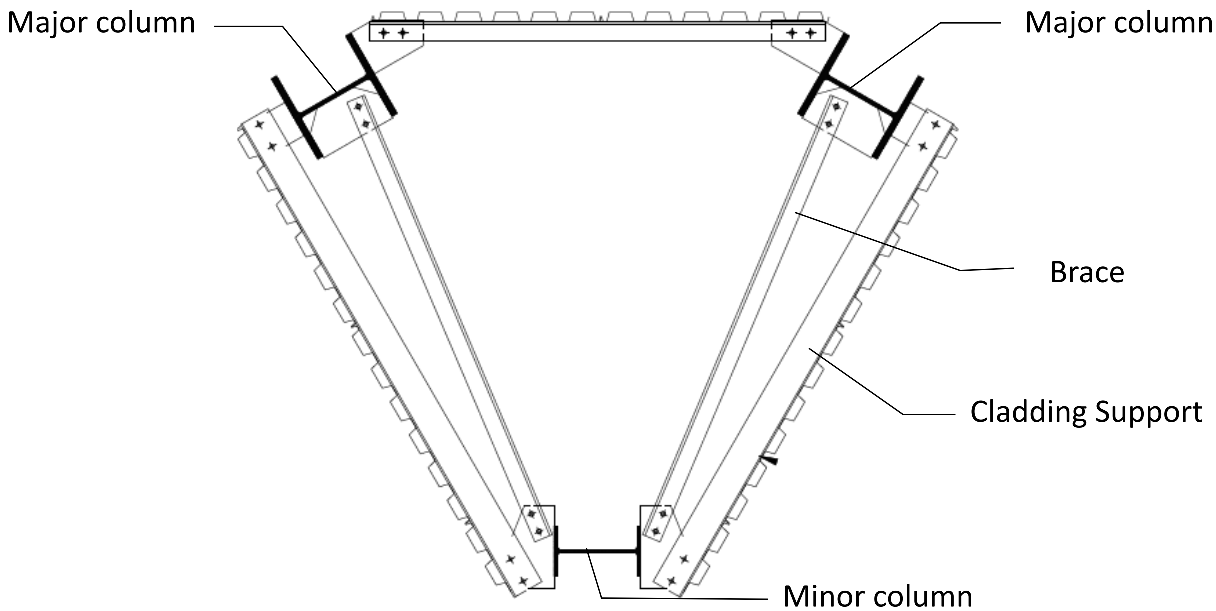

Figure 2 – Plan View of Tower Leg

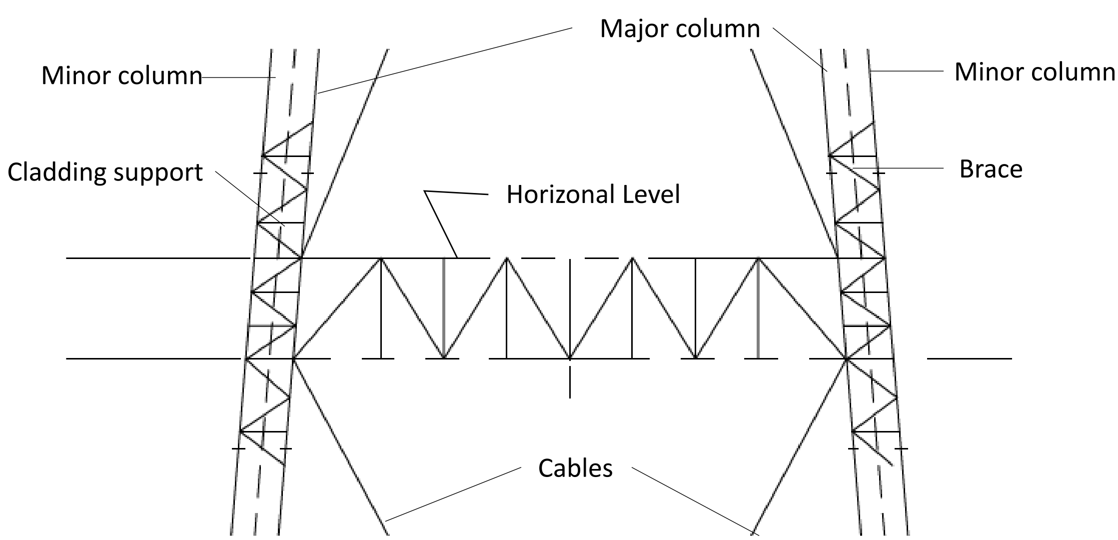

Figure 3 – Partial Tower Elevation Showing Two Legs and One Horizontal Level

Figure 4 shows the typical cross section of horizontal Levels 2 through 5. These levels are also triangular in shape and are formed by three wide flange steel "chord" members interlaced with diagonal and vertical wide flange members. Level 6 is of similar construction except that it is rectangular in cross section, rather than triangular.

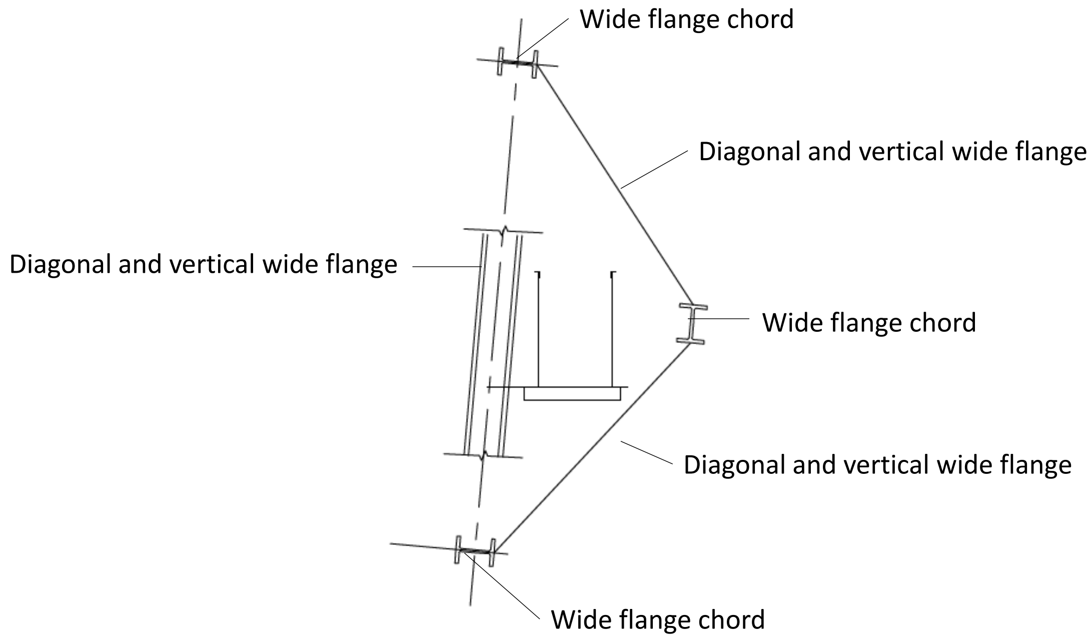

Figure 4 – Cross Section of Typical Horizontal Level

The region where the horizontal levels join the legs, illustrated in Figure 5, is extremely complex with all the various components, including columns, chords, diagonals and horizontal struts intersecting at angles to each other, both in plan and in the vertical plane. At each of these intersections, large steel gusset plates oriented in the horizontal and vertical planes connect each of these members. Figure 6 illustrates a few of these typical connections.

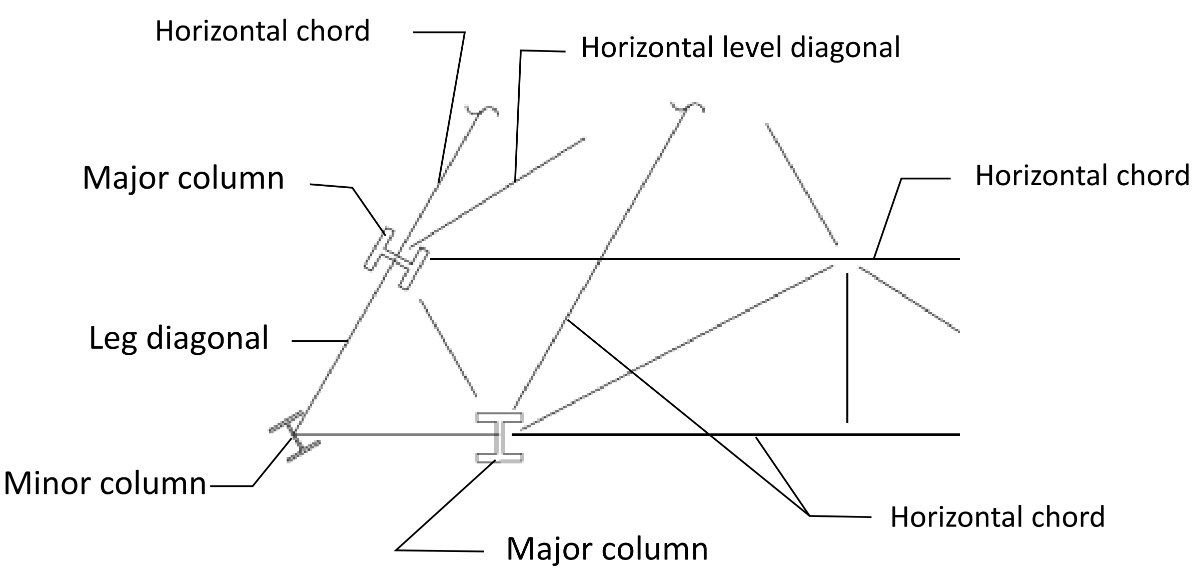

Figure 5 – Typical Horizontal and Leg Intersection

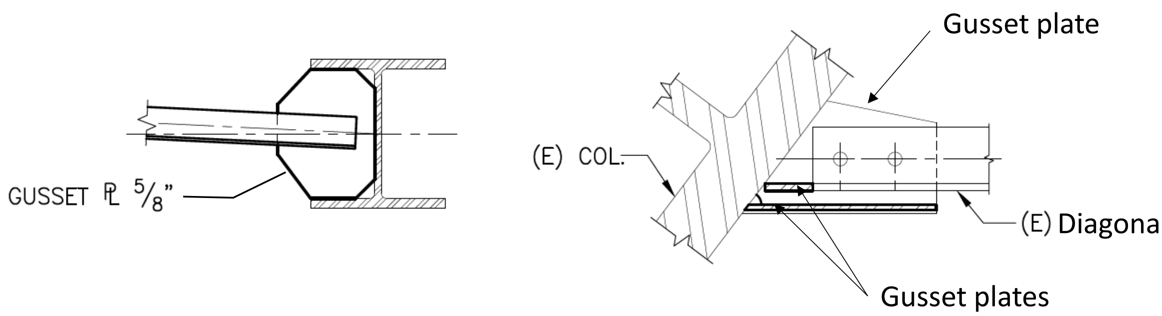

Figure 6 – Typical Connections of Structural Members

4. WIND REINFORCEMENT

Wind and seismic forces tend to push the Tower laterally, i.e., to the side. Figure 7 is an isometric view of our analytical model of the Tower, showing how wind and earthquake forces deform the structure to the side. The figure shows two isometric views of the structure superimposed on top of each other. The black isometric shows the Tower in a static, that is, undeformed position, as it typically exists when no significant wind or earthquake forces are acting. The blue isometric shows, in exaggerated form, the lateral (sideways) deflection of the Tower under wind forces. In this figure, the deformed shape shows how the structure would be displaced to the right, which is towards leg C, due to the wind blowing against Tower face A-B.

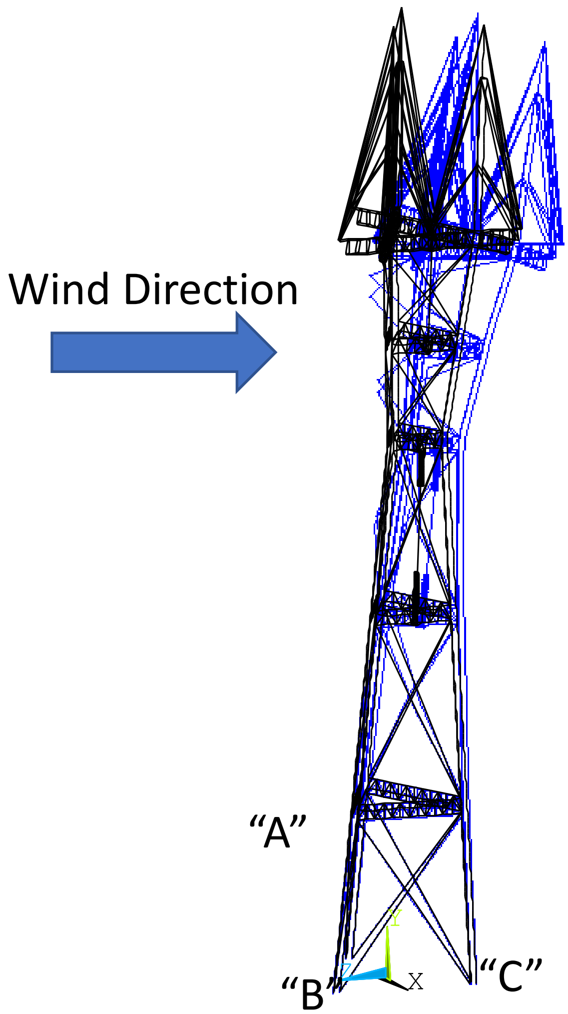

Figure 7 – Isometric Views of The Tower In Deformed And Undeformed State

Under the action shown in this figure, the wind forces tend to put compression on leg "C" while placing legs "A" and "B" into tension. In addition to these compressive and tensile forces, the legs are also forced into bending, which induces more compression or tension on the major and minor columns that form each of the legs.

As part of our design of structural modifications for the repacking project in 2016, we retained the firm of Rowan, Williams, Davies and Irwin (RWDI) to perform site-specific wind hazard analyses of the Sutro site and also to conduct wind tunnel testing of a model of the Tower. This is a state of art technique permitted by the SFBC and commonly used to determine design wind loads on major high-rise buildings and long-span bridges. We then applied the wind loads provided by RWDI, based on their wind tunnel test to our structural analysis model of the Tower, to determine the required strength of each of the columns, chords, braces, struts, and their interconnections. We found that the wind forces, associated with the present SFBC criteria for design of new essential structures increased the required strength of some of the existing columns by as much as 50%.

These increased wind forces meant that in order to comply with the current SFBC requirements for new essential buildings, we would have to increase the size of some existing columns forming the legs by 50%, assuming that we could do this reinforcement in a symmetrical manner. That is, if an existing column had a weight of 100 pounds per foot, after reinforcement, it would weigh 150 pounds per foot. Figure 8 illustrates one such form of symmetric strengthening. In the figure, two steel plates (shown cross-hatched in the figure) are added to either side of the web (horizontal piece) of the column section. The plates are balanced about the sides of the column and retain its symmetry.

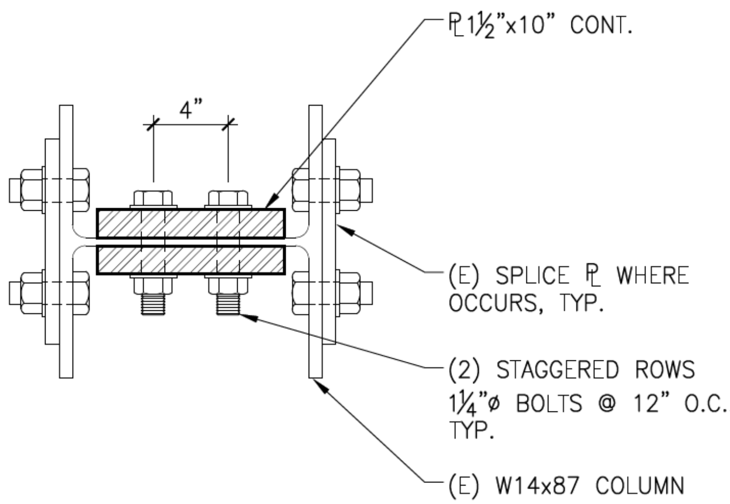

Figure 8 – Example of Symmetric Column Reinforcement

Unfortunately, because of the many interferences caused by the gusset plate attachments of members that connect to the column along its length, it is not physically possible to reinforce all of the columns in a symmetric manner. This required us to design unsymmetric reinforcement, such as that illustrated in Figure 9. This reinforcement, shown as cross-hatched plates in the figure, is located to one side of the column center line, and because of this, induces substantial bending stress in the column, making it less effective. The result is that substantially larger and heavier plates are required to do the reinforcement in this manner. This substantially increases the required amount of steel reinforcement.

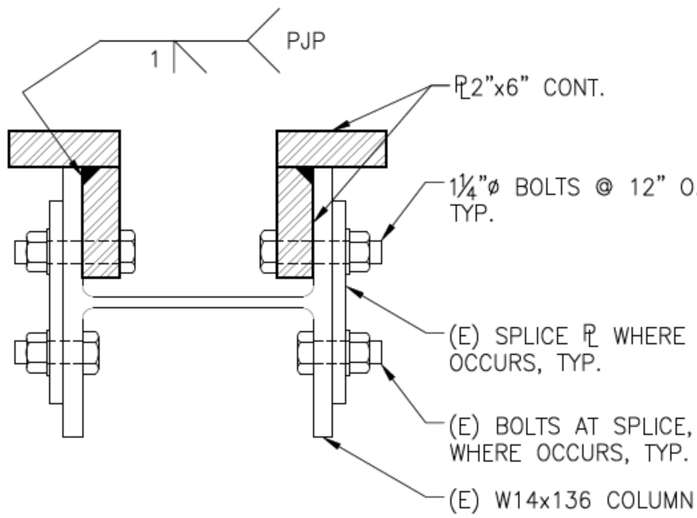

Figure 9 – Example of Unsymmetric Column Reinforcement

In 2017, we completed a preliminary design of the Tower upgrade to the 2016 SFBC using details of the type illustrated in Figure 9. We found that the required strengthening amounted to an addition of 676,000 pounds of steel to the Tower, or approximately 17% of its total existing weight.

Upon learning of this, we retained the firm of Cermak, Peterka, and Petersen (CPP) to perform a peer review of the RWDI wind loading study. CPP suggested that a substantial reduction in wind loads could be obtained if cladding on the legs of the Tower was removed. In response, RWDI updated their study and found we could obtain a substantial reduction in the wind loading. We performed an alternate design of the Tower upgrade (for wind and seismic loading) with the cladding removed from the legs and found that only 84,000 pounds of reinforcement would be necessary (as opposed to the 676,000 pounds needed with the cladding on).

We presented both designs to an external Engineering Design Review Panel retained at the request of the Department of Building Inspection. The external peer review, consisting of Dr. Andrew Whittaker of the University of Buffalo and Dr. Brian McDonald of Exponent Failure Analysis, concurred that removal of the cladding was the preferred and more proper approach.

In 2019, the Department of Building Inspection issued a permit for voluntary structural upgrade of the Tower to bring it into compliance with the 2016 SFBC requirements for new essential buildings, assuming cladding on the legs removed. The upgrade work was considered voluntary because under the SFBC, other modifications needed as part of the repack project were not sufficient to trigger a mandatory upgrade. Work for the permitted reinforcement is now complete and the Tower is fully compliant with the structural provisions of the SFBC, providing that the cladding remains removed.

5. CURRENT SITUATION

At this time, the work necessary to bring the Tower into compliance with the present SFBC, with the cladding re-installed on the legs in its original triangular configuration would include:

1. Removal of much of the reinforcement installed as part of the recently completed upgrade (42 tons).

2. Installation of the added reinforcement necessary to bring the structure into compliance (338 tons).

This would require transporting to, or removing from the Tower, more than 380 tons of structural steel, in some cases as high as 1,000 ft above the roofs of neighboring homes. Further, replacement of the cladding itself would require lifting an added 24 tons of material (the cladding) onto the Tower. Although standard construction safety measures would be in place throughout this operation, it would place the neighboring homes at increased risk during construction.

6. CONCLUSION

We conclude that from a perspective of structural safety, the preferred approach is to leave the legs unclad. This will avoid years of construction, and all of the attendant risks and disruption in the middle of the dense residential neighborhood. Further, in its current configuration, the Tower fully complies with the requirements of the repack conditions of approval and the SFBC structural criteria for essential structures.

Sincerely yours,

Ronald O. Hamburger, SE
Senior Principal
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cc: Kristen Thall-Peters, Cooper White & Cooper