28 December 2021

Mr. Neville Pereira
Deputy Director Permit Services
City and County of San Francisco
Department of Building Inspection
49 South Van Ness Avenue
San Francisco, CA 94103

Project 147041.10 – 301 Mission Street
Perimeter Pile Upgrade
Projection of Building Settlement Through Construction Completion

Dear Mr. Pereira:

This letter responds to Director O' Riordan's request that we provide projections of the expected building settlement behavior throughout the remaining construction period, as a precondition of construction resumption.

1. BACKGROUND

The building at 301 Mission Street, San Francisco, California, also known as the Millennium Tower, is a fifty-eight-story residential building constructed in the period 2005-2009. Located at the southeast corner of Mission and Fremont Streets, and just north of the Salesforce Terminal, the Millennium Tower is founded on a 10 ft thick, heavily reinforced concrete mat, supported by 942 precast, prestressed concrete piles extending approximately 80 ft below grade into the Colma formation, a dense clayey and silty sand. Beneath the Colma formation, the site is underlain by approximately 160 ft of marine and alluvial deposits, the upper layers of which are a stiff clay material known locally as Old Bay Clay. The surface of the Franciscan formation bedrock lies at a depth of approximately 250 ft below grade.

The building has experienced excessive, non-uniform settling since construction, with the most substantive settling having occurred near the building's northwest corner, resulting in a current displacement of the roof of approximately 24 in. to the west and 8 in. to the north. Geotechnical engineers concur that this behavior is primarily due to consolidation and secondary compression of the Old Bay Clay soils under the influence of the building's weight, and prolonged dewatering of soils to accommodate adjacent construction projects. Tilting is a result of the non-uniform stratigraphy and strength of soils across the site and the influence of adjacent construction. Settlement is monitored through periodic surveying of a series of settlement markers in the basement. Tilt is measured using automated total stations located on adjacent buildings and sited on prisms mounted on the building facade. Detailed survey data is available from 2009 onward, and since January 2021, weekly surveys have been conducted.

In 2019, building ownership applied for a building permit to construct a voluntary foundation upgrade under the provisions of the San Francisco Existing Buildings Code, Section 403.9. In October 2020, the City issued building permits for an indicator pile program, the project itself, and the associated shoring. The upgrade permit covers the installation of fifty-two piles, spaced at approximately 6 ft on center adjacent to the north (Mission Street) and west (Fremont Street) building faces; construction of an extension of the existing 10 ft thick reinforced concrete mat foundation to encompass the new piles; and jacking of 800 kips of load from the existing building onto each of the new piles. The goal of this design is to relieve a portion of the stress on the Old Bay Clay soils along the building's north and west sides, and in so doing, arrest further settlement at the building's northwest corner, while recovering a portion of the building's tilt through continued secondary compression of the Old Bay Clays located to the south and east of this corner. The upgrade will also enhance the seismic resistance of the building's foundation. To assure that load jacked off the existing foundation is transferred to bedrock, rather than re-imposed on the Old Bay Clays through skin friction on the new piles, the pile design incorporates a 36 in. diameter steel outer casing extending through the Colma formation and into the Old Bay Clay, and an inner 24 in. diameter, lubricant-coated, steel-cased, reinforced concrete pile, extending to, and socketed into the bedrock.

Construction was initiated in November 2021, with site clearance and relocation of utilities. In February 2021, the contractor installed an indicator pile but was unable to maintain the rock socket in an open condition. In April 2021, the contractor installed a second indicator pile, using a modified installation technique in which the 24 in. steel casing was extended into the rock, then withdrawn as grout was placed by tremie. This pile was successfully tested.

During the period July 2018 through July 2020, survey data indicated the building was settling at an average rate of about 1/3 in. per year, while tilting to the west and the north at rates of approximately 3/8 in. per year, as measured at the roof. During the latter part of 2020, before any construction had occurred, and until May 2021, when piling activity commenced, the rate of tilting to the west had increased to about 2-1/2 in. per year. In May 2021 the contractor initiated the installation of 36 in. casings for the production piles along Fremont Street, completing this work at the end of June 2021. During this period, the building tilted approximately 2-1/2 in. more to the west than would have occurred at the pre-construction tilt rate, which we judged to be acceptable. In early July, the contractor started installing 36 in. diameter casings along Mission Street, and we noted a modest increase in the rate of tilting to the north, while tilting to the west moderated. In mid-July, the contractor started installing

24 in. piles along Fremont Street, simultaneously with the casings on Mission Street. We noted that this again resulted in an increase of the tilt rate towards the west, and on 30 July, I advised the project to halt installation of 36 in. casings, to allow us to understand the effect of installing the 24 in. piles alone. Then, after three more 24 in. piles were installed, on 22 August, I ordered a halt of all piling work, to allow analysis of this settlement increase and to determine if alternative means of pile installation could be developed, that would have less impact on the foundation's behavior. At that time, thirty-three 36 in. diameter casings and six 24 in. diameter piles had been installed. Figure 1 shows the locations of these casings and piles.

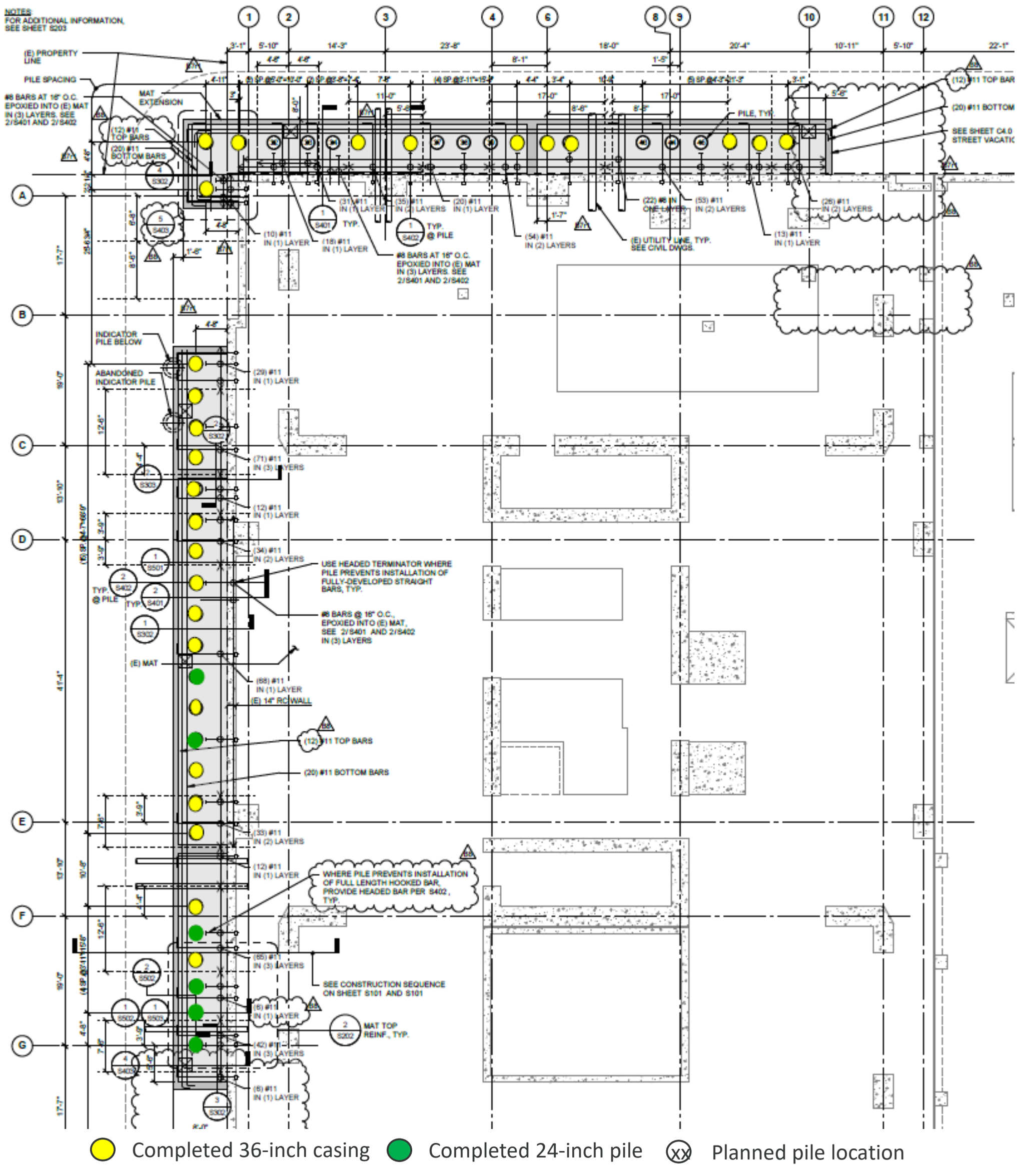

Figure 1 - Piles Installed as of 22 August 2021

Working with the contractor, we developed improved techniques described below for both the 36 in. and 24 in. piles. In October 2021, the project initiated a pilot program under which three casings and three piles were installed to test the effectiveness of the new installation procedures. This pilot program was successful.

2. CONSTRUCTION TECHNIQUE

Prior to installing piles, the contractor installed a guide wall system adjacent to the north and west sides of the building. This guide wall system is a 4 ft deep, reinforced concrete structure with square vertical openings centered at each design pile location. The guide wall serves the dual purpose of acting as a template for placement of the 36 in. casings and also transmits surcharge loads from the cranes used to install the piles sufficiently far below grade to protect the building's basement walls from overstress.

The 36 in. piles are installed through the guide wall template using a rotary drilling system in which teeth at the base of the casing are used to cut into the soil as the casing is rotated and pressed into the ground. The casing is pushed into the ground a distance of 10 to 20 ft, and then an auger bucket is used to remove soils from inside the casing. Casings are installed in maximum 40 ft lengths, with complete joint penetration (CJP) groove weld splices between sections. This process is repeated until the casing is tipped into the top of the Old Bay Clay materials, at a depth of about 105 ft below ground level.

The 24 in. casings are installed using the Reverse Circulation Drilling (RCD) technique. In this technique, the 24 in. casing is lowered into the center of a previously installed 36 in. casing, with a drill string housed within the 24 in. casing. The drill bit is lowered through the base of the 24 in. casing and rotated and "fired" that is cycled up and down, much like an impact hammer, to loosen soils ahead of the casing. Air and water are circulated down the drill string as drilling progresses to lift the loosened soil out of the casing, as the drill string and casing are simultaneously advanced downward. As with the 36 in. casings, 24 in. casings are installed in maximum lengths of 40 ft, with welded splices between sections. Once the 24 in. casing is advanced to the design pile tip elevation, the drill string is removed, a hollow reinforcing steel bar is inserted to the tip of the casing and used as a tremie to flow grout into the casing. As the grout is placed, the casing is withdrawn to an elevation about 20 ft above the top of the bedrock, to allow the grout to contact and bond with the surrounding soil/rock for load transfer.

3. PROBLEM ANALYSIS

Review of the survey data and drilling techniques suggested two potential sources of increased building settlement during pile installation. The first of these is over-excavation, and the second is vibration. Over-excavation simply consists of removal of more soil from beneath the tips of the existing building support piles, then is filled with new pile. Soil pressure associated with the building weight and that of the soils above then press inwards on the soil surrounding the piles to close the voids left behind by the over-excavation, resulting in volume change of the soil mass below the piles and settlement.

We identified several potential sources of over-excavation. When the 36 in. casings are installed, and the inside of the casing is excavated, there is potential for the soil and water pressure within the casing, at its base, to be less than that within the soil mass surrounding the casing tip. This pressure imbalance can force soil from under and around the casing tip into the casing where it is excavated and removed by the bucket. Two means are available to prevent this. One is to maintain a plug of soil at the base of the casing that has sufficient adhesion and/or friction with the casing inner wall to resist the differential pressures. The second is to maintain a sufficient depth of water or drilling fluid within the casing above the soil plug to minimize the pressure differential. The contractor did not use drilling fluid. Review of installation logs from the thirty-three previously installed 36 in. diameter casings indicates that both the soil plug depth and water column height was highly variable and at times, was likely insufficient to prevent over-excavation, particularly when the casing tip was within the Colma formation.

A second source of potential over-excavation is associated with the speed with which the auger bucket, used to excavate the soil plug, is withdrawn from the casing. Rapid removal of the auger bucket could cause a temporary suction pressure between the bucket tip and soil plug, again increasing the differential pressure inside and outside the casing. Also, rapid removal of the auger bucket could result in turbulent flow of water around the sides of the bucket, scouring the soil plug and reducing its effectiveness. No data is available to indicate the speed with which the auger bucket was handled during past production installations.

Potential sources of over-excavation during 24 in. pile installation include 1) the use of an over-size drill bit, and 2) the use of excessive air and water pressure during drilling. The initial installation of 24 in. piles employed a drill bit with deployable wings that extended 3/8 in. outside the casing outer wall. This created a 3/8 in. thick, open annulus around the 24 in. casing. The use of excessive air and or water pressure to lift spoils out of the casing could potentially scour material at the tip of the drill bit, creating a still larger annulus.

The Colma formation, upon which the existing building is founded, is a granular material. Vibration of granular materials can result in their densification and volume change. Review of the survey data for the period during the installation of casings and piles, indicated that settlement seemed to intensify as more casings and piles were installed. This suggested that previously installed casings and piles may have been serving as vibration transmission paths from the street level, inducing sufficient vibratory energy into the Colma formation to densify it. In addition, the impact hammer action of the RCD drilling process creates vibration at the drill bit, which emanates outward to the surrounding soil.

4. MODIFIED TECHNIQUE

To address the potential for over-excavation during installation of 36 in. piles, John Egan, the Geotechnical Engineer of Record, specified a table of minimum permissible soil plug lengths and water column elevations within the 36 in. casing, corresponding to the different soil strata. In addition, the contractor proposed the use of a bolted coupling to replace the CJP weld splices in the casing sections and reduce the time the casing tip would dwell in the Colma formation. Also, since completing the splices remained time-consuming, Mr. Egan specified the elevations for splices so as to minimize the amount of time that the open casing tips would be present within the Colma formation at a depth below the existing pile tips.

To address potential over-excavation during the 24 in. pile installation, we worked with the contractor to develop a reduced-size drill bit that would project only 1/8 in. beyond the casing outer wall. Further, we specified limits on the air and water pressure used to lift loosened soil from the casing.

To minimize potential vibratory compaction of the Colma sands we explored two measures. One is to selectively demolish the guide wall around the previously installed casings, to eliminate direct contact of the casings and guide wall and reduce the potential transmission of vibration down the casings. A second measure investigated is the use of rubber mats beneath the cranes used to install the piles, so as to isolate vibration associated with crane operation from the guide wall and mat. However, Response Dynamics of Oakland, California, a vibration consultant retained by the project, advised that the use of rubber mats could potentially increase vibration transmission, depending on the spectral characteristics of vibration transmitted by the cranes and the natural frequencies of the crane/mat system. Response Dynamics advised that it would be preferable to take vibration readings, during pile installation, prior to selecting a rubber mat specification, to assure the isolation, if needed, would be effective.

5. PILOT PROGRAM

In September 2021, the project requested, and the City approved, a program of limited pilot installations of additional 36 in. casings and 24 in. piles. The purpose of this pilot program was to:

1. Obtain information on the effectiveness of the installation technique modifications described above.

2. Provide vibration data to permit further assessment of the extent that vibration was contributing to the increased settlement rate, and also provide a basis for design of a crane isolation system, if needed.

3. To provide information on the settlement and tilt rates of the building associated with casing and pile installation using the improved techniques.

The contractor installed three 36 in. casings (32, 33, and 34) in the period 12 October through 4 November and three 24 in. piles (26, 30, and 31) in the period 15 November through 15 December, using the new techniques. In addition, the design team, and representatives of Dan Brown & Associates, a third-party geotechnical engineering consultant, with particular expertise in deep foundations retained by the homeowners on behalf of the City, provided enhanced surveillance of the installation through on-site monitoring. We also retained a licensed surveyor to provide hourly readings of building settlement and tilt as pile operations progressed, as a control measure, to enable us to halt work should settlement or tilt become excessive.

The contractor successfully completed the pilot pile installations without producing increased settlement or tilting of the building.

6. SURVEYING DATA

This section presents summary data on building settlement and tilting obtained during the period starting in 2009 and extending through the recently completed pilot pile program. Initial data was obtained by Arup under their services in support of the design and construction of the Transbay (now Salesforce) Transit Center located immediately to the south of the Millennium Tower. Arup established an array of 38 settlement markers on the Millennium Tower's base mat in 2009 and conducted monthly surveys of the elevation of these settlement markers through completion of the terminal project in 2018. In 2016, Langan Associates mounted a series of prisms on the building's north and west facades, at multiple levels, together with total stations on adjacent buildings, to record the movement of these prisms in three dimensions. In 2020, Slate Geotechnical Consultants assumed responsibility for the collection of data from both the settlement markers and prisms for the balance of the Perimeter Pile Upgrade construction and for a period of 10 years after completion.

Figure 2 presents a summary of data obtained by Langan as produced in their final report in July 2020. This graph shows the average vertical settlement, tilt to the west and tilt to the north, as measured by Langan using the exterior-mounted prisms during the period extending from January 2017 through July 2020. Superimposed over the top of the plots are a series of straight lines indicating the long-term rate of increase of settlement and tilt during the period July 2018 – July 2020. In July 2020, Langan reported 16 in. of average vertical settlement, relative to the initial design elevations, 16.5 in. of tilting to the west, and 6.6 in. of tilting to the north, as measured using prisms at the top of the exterior facade. It should be noted that the scale of settlement shown in the figure has been adjusted to "zero" at the time Langan initiated their surveys. During the two-year period from July 2018 through July 2020, the data indicates average vertical settlement at a rate of approximately 0.37 in. per year, tilting to the north at a rate of approximately 0.31 in. per year and tilting to the west at a rate of approximately 0.38 in. per year.

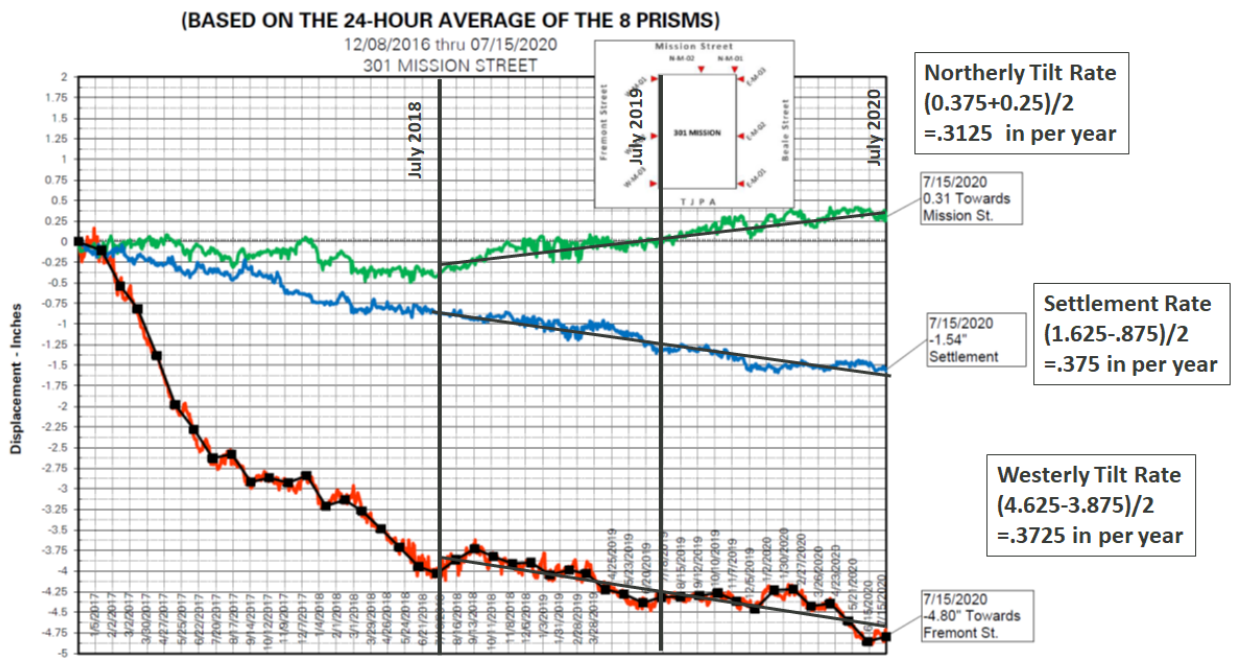

Figure 2 - Langan Survey Data – January 2017- July 2020

Figure 3, prepared by Slate Geotechnical Consultants, shows the survey data obtained from settlement markers on the base mat starting in January 2021 through the present. The figure shows the settlement over time measured at each of thirty individual settlement markers and the average of all thirty markers indicated as "average planar" in the figure. Four periods of activity are noteworthy in this figure: 1) the period from January 2021 through April 2021, during which construction activity was limited to clearance of utilities and site obstructions and the test pile program previously described; 2) the period from 1 May 2021 through 22 August 2021, during which the installation of thirty-three 36 in. diameter steel casings and six 24 in. piles occurred; 3) the period extending between 22 August 2021 and 12 October 2021, during which there was a moratorium on construction activity; and lastly, the period between 12 October 2021 and 15 December 2021, during which the pilot pile installation program occurred. We refer to these four periods as: 1) pre-construction: 2) production piling; 3) moratorium; and 4) pilot program, respectively. During the pre-construction period, the average planar settlement increased at a rate of approximately 1/3 in. per year, which is similar to the 0.38 in. per year shown by Langan during the prior two years. During the production piling period, settlement increased to a rate of 3 in. per year, increasing as more casings and piles were installed. Following the institution of the moratorium, the settlement quickly returned to an average rate of about 1/2 in. per year, slightly more than before the piling, but still similar to that recorded by Langan in the period 2018-2020. The rate of 1/2 in. per year has been maintained throughout the pilot program period.

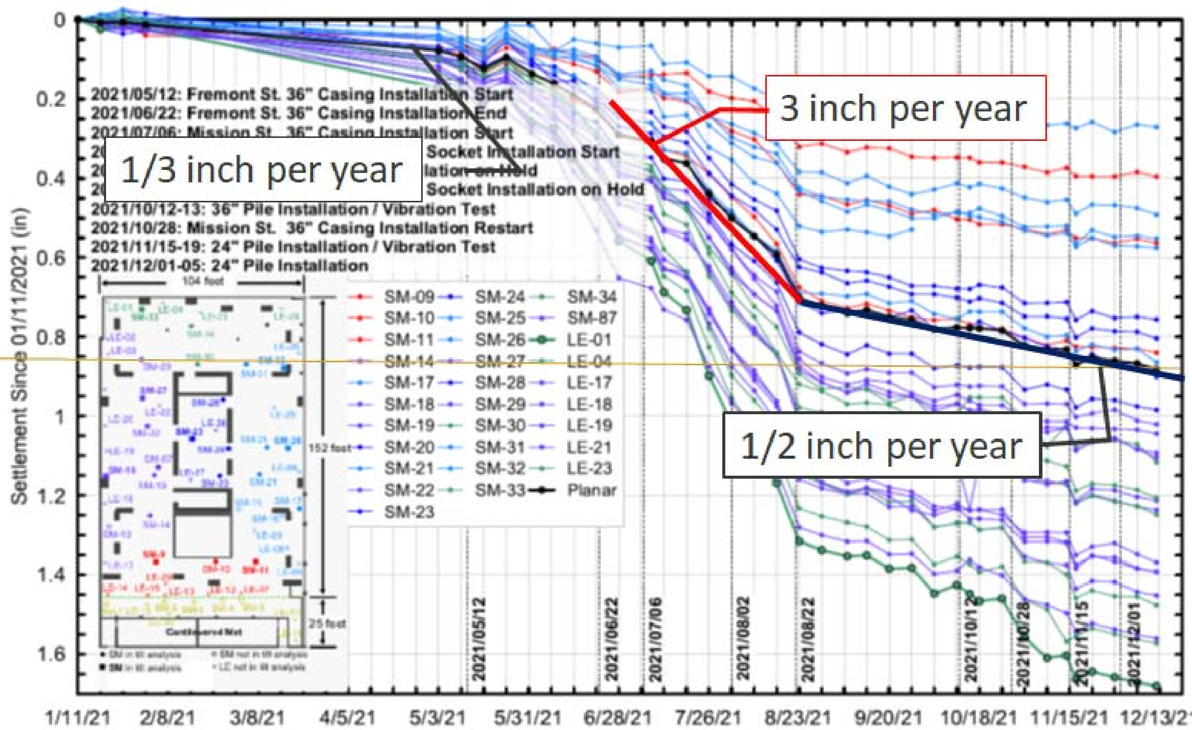

Figure 3 - Survey Data by Slate Geotechnical, January – December 2021

Figure 4 presents a plot of building tilt from January 2021 through the present as measured by the lateral deflection of the roof using the same prisms installed by Langan. Four plots are included in the figure: 1) east-west prism data (red); 2) east-west roof deflection inferred by calculation from an assumed rigid body rotation of the building (light blue); 3) north-south prism data (green) and 4) north-south deflection inferred by calculation assuming rigid body rotation (dark blue). The figure shows tilting to the west at a rate of 2-1/2 in. per year in the pre-construction period and 3-1/8 in. per year during the moratorium and pilot program periods. Similarly, tilt to the north is shown as: approximately 1 in. per year during the pre-construction period and 3-1/4 in. per year during the moratorium and pilot program periods. The pilot program has not significantly affected the tilting rate either to the north or west relative to that which occurred during the moratorium, and in fact, the plot shows some decrease in the rate of tilt to the north and west during the 24 in. pilot pile installations.

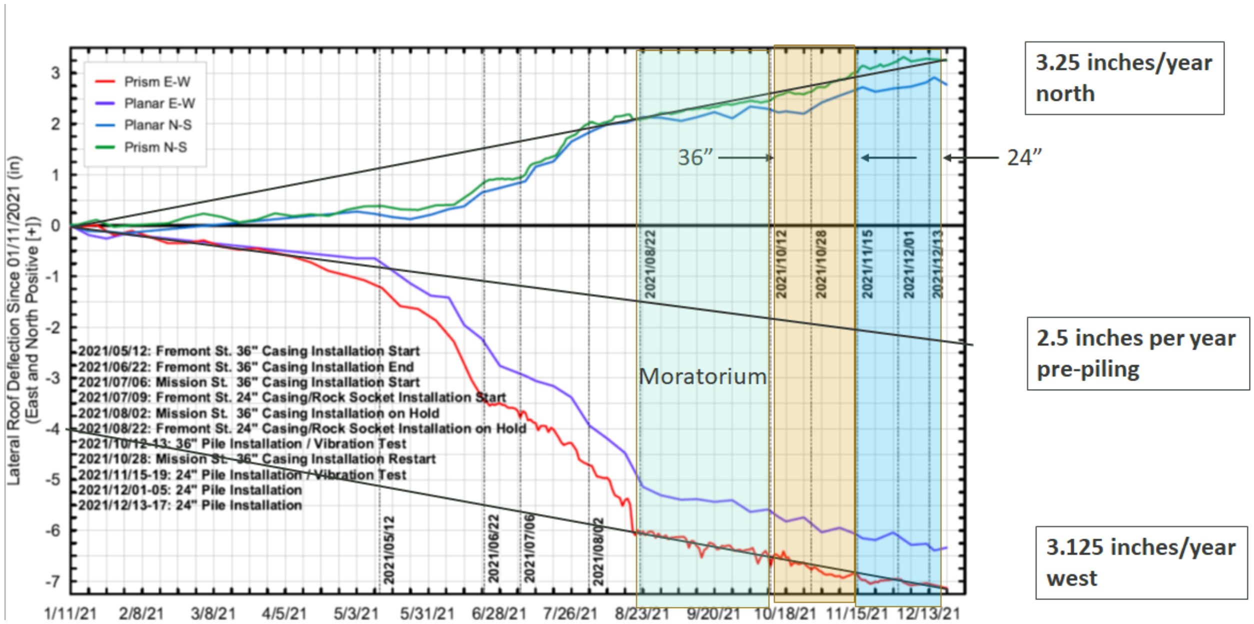

Figure 4 Building Tilt Survey Data January – December 2021

Figure 5 shows the locations of vibration sensors during the pilot installations of 36 in. casings, at locations 32, 33 and 34, and also during the installation of 24 in. pilot piles at locations 30 and 31. Figure 6 shows the mean and maximum root mean square velocities recorded within the Colma formation during the installation of the 36 in. casing at location 33. The maximum vibration amplitudes recorded at depth were on the order of 600 micro-m/s and occurred during excavation of soil from within the casing using the auger bucket, as the casing tip was extended from the 70 ft to 90 ft depth, that is within the lower Colma formation.

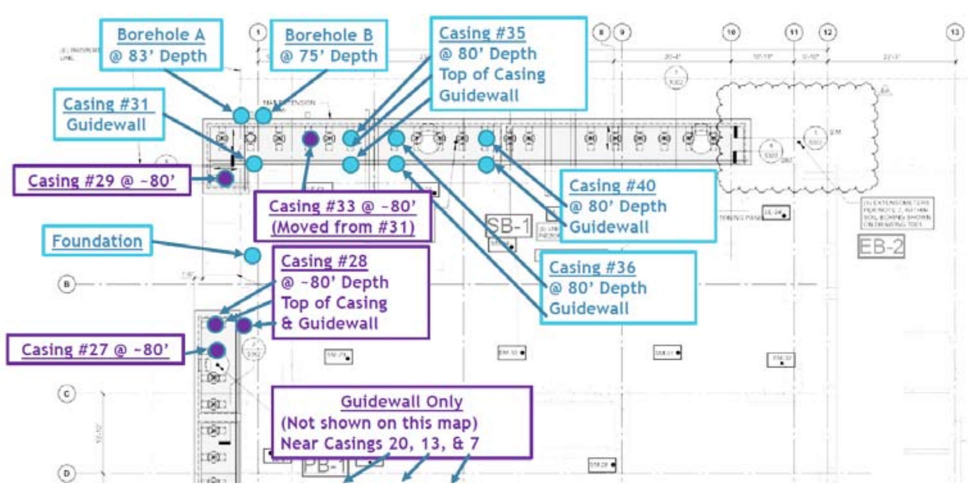

Figure 5 - Locations of Vibration Sensors

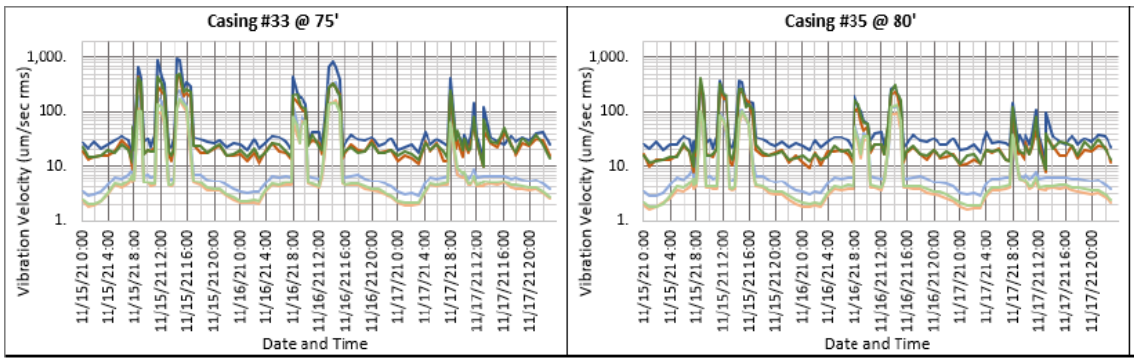

Figure 6 - Mean and Maximum Vibration Levels within the Colma Formation During Installation of Pilot Casing 33

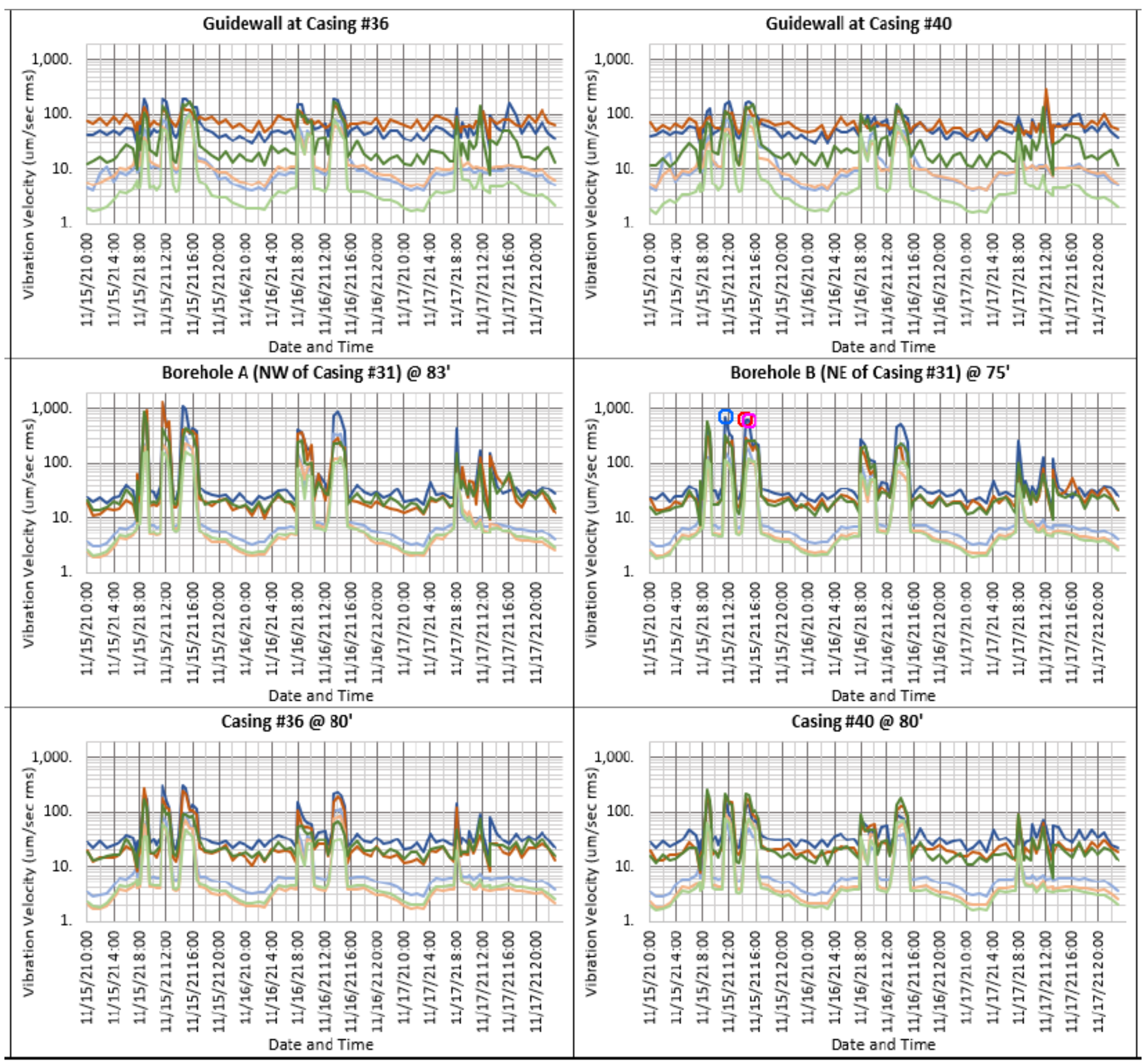

Figure 7 - Mean and Maximum Vibration Levels within the Colma Formation and at the Guide Wall During Installation of Pilot Pile 30

Figure 7 shows the mean and maximum root mean square velocities recorded at depth and at the guide wall during the installation of the 24 in. pile at location 30. The maximum vibration amplitude within the Colma sand was somewhat higher than for the installation of the 36 in. casing, with peak root mean square velocity of about 1,000 micro-m/s. This amplitude occurred as the 24 in. pile was advanced through the soil plug within the 36 in. casing at 100 ft below grade and decreased as the drill tip progressed deeper into the underlying soil. Also, the amplitude of velocity at the guide wall was approximately 1/5 that recorded at depth within the soils. Not shown in the figure but evident from spectral analysis of the vibration waveform is that the frequency of maximum energy content within the Colma sands matches the firing rate for the drill bit. We interpret this as evidence that vibration within the Colma formation during 24 in. pile installation is primarily caused by firing of the drill bit, that transmission of vibration from the guide wall through the casings is not a significant factor, and that isolation of the guide walls from the casings and the crane from the guide wall is not necessary. This is particularly evident given that the installation of pilot pile No. 26, occurred without separation of the casings from the guide wall and did not have a significant effect on building settlement or tilt.

7. PROJECTED PERFORMANCE

The Department of Building Inspection has requested that prior to resumption of production piling, the project present a projection of expected additional building settlement and tilt through project completion. As previously discussed with the City's review panel (EDRT), the project team believes that to minimize the impact of accelerated titling the building is now experiencing, absent any construction activity, it is important to complete project construction expeditiously. Given restrictions on construction-related noise during nights, the ability to speed construction through multiple labor shifts is not possible. Therefore, we believe the best path forward is to reduce the number of piles installed, while simultaneously increasing the jacking load per pile. To this end, we are preparing a submittal to the EDRT of a revised design comprising a total of 18 piles with a jacking load of 1,000 kips per pile. Mr. Egan and his team have conducted settlement analyses for this design, similar to those prepared in support of the original 52-pile design, to predict the building behavior over 40 years. These analyses indicate that the 18-pile option is sufficient to achieve the project design objectives of arresting settlement at the building's northwest corner while obtaining recovery of a substantial portion of the tilt that has occurred over the years. We have also performed structural analyses that confirm the tower and foundation will perform acceptably under this retrofit alternative.

The contractor has prepared an updated construction schedule for the 18-pile design. This schedule, predicated on a resumption of production piling on 3 January 2022, shows that jacking of load onto the piles can be accomplished in August and September of 2022, with substantial completion of the project occurring in early 2023. On this basis, we have formulated our projection of the expected building performance over the remaining construction duration. Doing this, we use the rates of settlement and tilt recorded during the past months, including both the moratorium and pilot casing/pile installation program, as these rates have remained constant throughout this period. In order to be conservative in our estimate, we project building performance at these rates through the end of December 2022, even though we project that load transfer will occur in September 2022 and that tilt recovery will begin at that time. With these assumptions, we project total additional building settlement over the remaining construction period of 1/2 in. (average of settlement markers) with additional tilt to the west and north of 3 in., as measured at the roof. This will result in total settlement, at the end of December 2022 of approximately 17 in., with total tilt to the west of 27 in. and total tilt to the north of 11 in.

These projected additional building settlement and tilt displacements are similar to those previously reviewed by the EDRT and accepted as being within the building's ability to safely resist additional settlement. We have recently submitted analyses to the EDRT indicating that the building is able to safely resist tilting of as much as 79 in. to the west and 30 in. to the north. Therefore, we are confident that the building retains substantial structural margin to safely resist the additional tilting and settlement we anticipate during the remaining construction.

The Department of Building Inspection also requested that we provide assurance that the building will remain serviceable given this additional tilting. The primary effects of tilting on building serviceability relate to the elevators and to an architectural wall at the port cochere. The elevators to the garage are located within the adjacent podium structure but are accessed from floor slabs within the tower. As the tower has tilted to the west, the gap between the elevator car and floor slab has exceeded that permitted by the elevator code. The HOA has contracted with Mitsubishi Corporation, the elevator maintainer, to correct this deficiency by adjusting the threshold. One of these elevators has been repaired, and the other will be repaired shortly.

The architectural wall at the port cochere has experienced distress as a result of differential building movement. The wall has been stabilized to prevent further damage. In addition, the HOA has contracted with a consultant to design repairs to this wall that will accommodate the anticipated additional settlement.

The HOA has retained a consulting firm to review the condition of plumbing running through the building. They report that the piping is currently serviceable and not in jeopardy of failure. They will continue to monitor this and make recommendations for repair/modification of plumbing as necessary to avoid failures.

Given the above measures, we do not anticipate further serviceability issues as building construction continues.

8. CONCLUSION

We conclude that it is important to expeditiously complete construction so that the heightened rate of settlement and tilt experienced over the past nine months can be arrested, and tilt recovery can initiate. We project that the construction of a reduced scope option can be substantially completed within 2022. Anticipated additional building settlement and tilt during this remaining construction period can be safely accommodated by the structure without impact on serviceability that cannot be mitigated through corrective work already planned.

Accordingly, we plan to re-initiate construction on 3 January 2022, with the installation of nine additional 24 in. piles required for the proposed reduced-scope project, using the improved procedures demonstrated effective in the recently completed pilot program. This work will be conducted under the current permit for construction while we work with the EDRT and the Department to obtain an amendment to the permit for the reduced scope plan. We will continue to employ the enhanced construction surveillance measures employed during the pilot program until the EDRT and Department agree that relaxation of these measures is appropriate.

Sincerely yours,

Date Signed: 12/28/2021

Ronald O. Hamburger, SE
Senior Principal
CA License S-2951 (Structural)
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cc: G. Deierlein
S. Vahdani
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