4 March 2020

Mr. Steve Minden
Mission Rock Partners, LLC
c/o Tishman Speyer
One Bush Street, Suite 450
San Francisco, California 94104

SUBJECT: Lightweight Cellular Concrete Geotechnical Performance Goals and Design Criteria
Mission Rock – Phase 1 Horizontal Development
San Francisco, California
Langan Project No. 750604203

Dear Mr. Minden:

This letter presents our recommended geotechnical design criteria for raising street grades with compensating lightweight cellular concrete for the Mission Rock Phase 1 Horizontal Development project in San Francisco, California. The results of our geotechnical investigation for the horizontal components of the Mission Rock Phase 1 project were presented in a report dated 31 October 2019. Information provided here is based on the subsurface conditions documented in the 31 October 2019 report and on the conclusions and recommendations provided in that report. Anyone relying on the recommendations here should be familiar the subsurface conditions, assumptions, and conclusions provided in that 31 October 2019 report.

Background

Existing site grades within the Phase 1 Development area are from about Elevation 97 feet to about 101.5 feet[1]. Site grades for the future streets and sidewalks will be raised to accommodate future sea level rise, with planned street grades up to about Elevation 104 to 104.5 feet and sloping down to meet the existing street grades at 3rd Street. If conventional soil fill is placed to raise grades, the load from this new fill would result in consolidation settlement in the underlying compressible clay (known locally as Bay Mud). Consolidation would be unacceptable for the project requirements. Therefore, the project team has elected to raise grades using permeable lightweight cellular concrete (LLC). However, because the LCC and street improvements will apply some load, some existing soil at the will need to be overexcavated and replaced with LCC to offset all new loads.

Additionally, the remaining fill below the LCC section is potentially liquefiable and can cause erratic settlement. Therefore, the project team has elected to improve the fill below the LCC to mitigate liquefaction.

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[1] Elevations based on topographic survey by Martin Ron, dated 2 July 2019, Mission Bay Datum (Old San Francisco City Datum plus 100 feet).

Performance Goals and Design Criteria for LCC

The geotechnical aspects of the LCC performance goals and design criteria for meeting those goals includes the following:

- Constructing streets and rights of way (ROW) founded upon LCC to limit future settlement and heave to acceptable levels and prevent hydrostatic uplift caused by sea level rise.
    - The new loads should be offset by at least 10 percent by overexcavating existing fill to a sufficient depth and replacing it with LCC.
    - The new LCC and overlying street sections should be designed to resist hydrostatic uplift with a factor of safety of at least 1.2 and 1.1 against future groundwater rise to the potential future (year 2100) mid-range and high-range groundwater level of 97.0 and 99.5 feet, respectively.
- Providing a suitable pavement substrate for the anticipated traffic loading.
    - LCC should be sufficiently strong to resist crushing under anticipated loading, including self-weight and from overlying improvements and temporary loads, such as heavy vehicle wheel loading.
    - LCC should be sufficiently stiff to provide an adequate substrate for the San Francisco standard pavement design.
- Allowing for future utility installation or repair using standard equipment, tools and methods.
    - LCC should be excavatable to allow for underground utility installation, repair, or other maintenance.
- Providing earthquake performance consistent with, or better than, traditional roadway construction in San Francisco.
    - LCC should perform adequately to provide vertical support of the roadway after a major earthquake.
    - Cracking of the LCC resulting from a major earthquake should not result in a significant decrease in the pavement lifecycle.
    - Pavement repair following a major earthquake should be equal to or less severe than traditional construction in San Francisco.

Geotechnical Evaluation and Engineering

Details regarding each of these criteria and the engineering background for each are provided in the sections below.

Load Compensation

To reduce the potential for new primary and secondary consolidation settlement caused by raising site grades and installing street improvements, the existing fill should be removed to a specified depth, and the resulting overexcavation should be backfilled using permeable LCC. The bottom elevation of the lightweight fill section should be determined such that the effective stress on the top of the Bay Mud following placement of the improvements is at least 10 percent less than the existing effective stresses. This reduction in effective stress will result in a "factor of safety" for net unloading (removed load/new load) of at least 1.1.

Within the new 60- to 70-foot-wide ROW, there will be new utilities, streets, sidewalks, light poles, and tree-planting areas between the building parcels. The evaluation for the required depth of overexcavation includes the weight of these new improvements, including the loads from new utilities, utility bedding and shading, the street and sidewalk pavement sections, trees, light poles, structural soil, and the increased density of improved fill that remains below the LCC. The following assumptions are included in calculating the required depth of overexcavation and placement of the load-compensating open-cell (permeable) LCC:

- Existing observed average high groundwater level is at Elevation 93 feet.
- Unit weight of brackish groundwater is 63 pounds per cubic foot (pcf).
- Target cast unit weight of the open-cell (permeable) LCC is 26+/- 2 pounds per cubic foot (pcf) with a minimum compressive strength of 50 pounds per square inch (psi) at 28 days.
- Target cast unit weight of the upper 2 feet of LCC is 30+/- 2 pcf with a minimum compressive strength of 80 psi at 28 days.
- Long-term (potentially fully saturated) unit weight of permeable LCC below groundwater is 68 pcf, resulting in a new buoyant (effective) unit weight of 5 pcf (68 pcf minus 63 pcf). This number is based on vacuum-pressure laboratory saturation testing, which indicates a potentially fully saturated unit weight of 63 pcf with an additional 5 pcf to account for potential variability.
- Unit weight of the existing fill varies from 110 (very loose sand) to 140 pcf (concrete and brick debris), with an average of approximately 125 to 130 pcf. A unit weight of 125 pcf is used for load offset calculations. Improved fill (beneath the new LCC section) is estimated to have a unit weight of 131 pcf—an increase of 6 pcf above the existing conditions.
- Pavement section is comprised of 8 inches of Portland cement concrete (PCC) overlain by 4 inches of asphalt concrete (AC), both with a unit weight of approximately 150 pcf. The pavement is underlain by 4 inches of aggregate base with a unit weight of approximately 130 pcf.
- Structural soil placed in the planter strips has a unit weight of 110 pcf. The width and length of the planting strips is different for each street section. The width of the structural

soil is approximately 6.5 to 13 feet and have been accounted for in the calculations at each section.

Using these values, the overexcavation and elevation of the bottom of LCC has been calculated such that the effective stress on the top of the Bay Mud after placement of the improvements will be at least 10 percent less than the existing effective stresses at the top of Bay Mud. We judge that, in using this approach, there will be a net unloading of the Bay Mud across the site, and the potential for a new cycle of primary consolidation will be low. In addition, the net unloading should significantly slow or retard any ongoing secondary compression settlement of the Bay Mud under existing loading within the street sections.

There may be a need for temporary backfill in localized excavations in LCC. Provided that the extent and duration are limited, these excavations can temporarily be backfilled with soil without causing new settlement. For these cases, a volume of up to 24 square feet of soil per linear foot of right of way can be placed for a duration of no more than 3 months. If the extent is larger or the duration is longer than these recommended values above, the use of temporary backfill should be evaluated case by case.

<u>Prevention of Hydrostatic Uplift</u>

To prevent hydrostatic uplift, open-cell (permeable) LCC will be used. The open-cell LCC will allow water to flow through the material, preventing excessive hydrostatic pressure from building at the bottom of the LCC section. The critical condition for hydrostatic uplift occurs when the LCC is only partially saturated. The assumptions used as the design criteria for the hydrostatic uplift check include:

- Existing observed average high groundwater level is at Elevation 93 feet.
- Unit weight of brackish groundwater is 63 pounds per cubic foot (pcf).
- Future (year 2100) mid-range groundwater level of Elevation 97 feet and high-range groundwater level is 99.5 feet[2].
- Target cast unit weight of the permeable LCC is 26+/- 2 pcf.
- Target cast unit weight of the upper two feet of LCC is 30+/- 2 pcf.
- Partially saturated unit weight of permeable LCC below groundwater is 50 pcf, resulting in a net buoyant unit weight of -13 pcf (50 pcf minus 63 pcf). This value is only used to check for hydrostatic uplift calculations.

The check for hydrostatic uplift compares the total stress at the base of the LCC against the theoretical hydrostatic pressure based on the future high groundwater levels. Each section of LCC should be considered adequate to resist hydrostatic uplift provided the factor of safety

[2] Groundwater levels have been taken from potential sea level rise levels provided in FEMA Guidelines.

against hydrostatic uplift is at least 1.1 when checking the high-range groundwater level of Elevation 99.5 feet and at least 1.2 when checking the mid-range groundwater level of Elevation 97 feet.

The LCC should be sufficiently permeable to prevent the buildup of excessive hydrostatic uplift pressure during fluctuations in the groundwater table. The tides in the San Francisco Bay generally change 5 feet or less over a period of 6 hours or longer (approximately 0.007 cm/sec). The water level measured in piezometers within the site fluctuates less than 1 foot when the tides change. Considering the likely rate of tidal fluctuations and the groundwater level fluctuations observed within in the site, we conclude that the material should have a minimum permeability of 0.005 cm/sec. The minimum permeability should be sufficient to prevent excessive hydrostatic uplift pressure on the LCC as the tides change. To mitigate the likelihood of the permeable LCC from becoming clogged with migrating fines from the surrounding soil and reducing the permeability, filter fabric should be placed at all interfaces where LCC is in contact with soil.

During construction, dewatering should be maintained until a sufficient thickness of LCC has been placed to prevent hydrostatic uplift using a using the observed high groundwater level currently encountered within the site of Elevation 94 feet.

Crushing Resistance

LCC should be considered adequate for support of the improvements in the new ROW provided the LCC has adequate compressive strength to resist crushing under anticipated loading, including self-weight, the load from overlying improvements, and temporary loads, including the heaviest anticipated fire truck, which represents the critical case for LCC crushing.

The LCC should have sufficient strength to resist crushing with a factor of safety of at least 2. Based on our calculations, we conclude LCC with a minimum submerged strength of 40 psi has a factor of safety greater than 2 for crushing under a tiller ladder truck tire or outrigger loads from an American LaFrance truck with a 105-foot-long ladder). Studies indicate the compressive strength of LCC reduces when saturated in brackish water. Based on test results, LCC saturated in brackish groundwater had a 28 days compressive strength as low as 80 percent that of LCC cured in a nonsaturated environment. Therefore, a target minimum compressive strength of 50 psi should be specified to allow for a 20 percent reduction in strength and still maintain a factor of safety of at least 2 under crushing.

Pavement Design

As described in the geotechnical report for the project, the standard City and County of San Francisco pavement section is being used. This pavement section consists of 4 inches of AC over 8 inches of PCC with an unconfined compressive strength of 4,500 psi. Although it is not part of the standard pavement section, a 4-inch-thick layer of aggregate base is detailed beneath the PCC. This composite section is not consistent with either rigid or flexible pavement design methodologies. However, we evaluated the pavement section using the design methodology per AASHTO Guide for Design of Pavement Structures. The results of our analysis indicate that the concrete section over a substrate with the strength and modulus of intact LCC is capable of supporting more than 11 million equivalent single-axle loads (ESAL). This ESAL value suggests that for a typical 20-year pavement design life, the pavement could support either 395 heavy trucks per day, including the fire truck or other trucks with three axles with the maximum legal weight at rear and a combined weight of 54,000 pounds (examples include dump trucks, garbage trucks, fire trucks, or full concrete trucks) or 500,000 light trucks per day what have two axles with a combined weight of 8,500 pounds (examples include box vans, utility trucks, or a pickup truck with a trailer).

Provided this number of ESAL's meet or exceed the expected performance for San Francisco City streets, we conclude that the LCC provides an acceptable substrate for the San Francisco City street pavement section.

<u>LCC Excavatability</u>

LCC should be excavatable to allow for underground utility installation, repair, or other maintenance. It can be excavated using standard tools, equipment, and methods, provided it is not too strong. LCC can be excavated in vertical cuts, allowing for smaller and more precise excavations for utility repair, without the need for shoring. Therefore, using LCC is beneficial for future work in the streets.

LCC with a maximum compressive strength of 300 psi is likely the upper limit for which LCC can still be excavated. The specification for the LCC specifies a maximum 28-day compressive strength of 200 psi. Because strength can continue to increase beyond 28 days, it is appropriate to specify 200 psi so that the LCC strength does not ultimately exceed 300 psi over time and is still excavatable.

<u>Seismic Design and Performance</u>

The Phase 1 project will be granted a permit under the 2016 San Francisco Building Code (SFBC). Strong shaking is expected during a major seismic event. The LCC will be subjected to several types of earthquake-induced loading, including (1) vertically propagating shear waves, (2) surface waves (e.g., Rayleigh waves), and (3) potentially differential ground movements caused by variation in depth to bedrock, thickness of Old Bay Clay, and thickness of Young Bay Mud.

One potential sources of damage to the LCC would be the horizontal cyclic shear stresses induced from vertically propagating horizontal shear waves. We have analyzed this condition, and our calculations show that LCC with a target unconfined compressive strength of 50 psi at 28 days (degraded to 40 psi) has sufficient strength to resist the cyclic shear stresses from these types of waves.

Considering that the LCC section is long (several hundred feet long) compared to its thickness (6 to 13 feet thick), it will be subjected to compression, tension, and shear and may locally crack when is subjected to surface waves or differential ground deformation, creating blocks of LCC. Because of the relatively rigid nature of the LCC, however, the LCC within each block will retain its original strength and stiffness and still provide support of improvements. The placement of LCC will be performed in lifts and segments; accordingly, cold joints will be created which should provide preferential cracking, and thereby limiting the extent of cracking.

If differential movement occurs at LCC cracks, the overlying pavement or sidewalk may crack and need repair after a major seismic event. The level of cracking expected in the pavement or sidewalks will likely be similar to or less severe than the cracking or distress to pavements or sidewalks at nearby sites where they bear on soil that has not been improved.

At locations where cracking occurs, mechanisms are in place that will reduce the likelihood of damage to the utilities. All underground utilities except district energy system (DES) piping are surrounded by bedding and cover sand or gravel. The bedding and cover materials are not compacted in place, and moderate differential movement along LCC cracks is expected to be accommodated in the bedding and cover material. The DES pipes consist of highly ductile high-density polyethylene (HDPE) piping that will be encased directly in the LCC. Considering the strength and ductility of the HDPE piping, we would not expect appreciable damage at locations where the LCC cracks. In general, we would expect better performance of the utilities within the LCC than at nearby soil sites; however, repairs may be necessary following a major seismic event.

We re-evaluated the adequacy of the LCC to support the pavement section in the case where the LCC has cracked because of a seismic event. As part of this evaluation we degraded the modulus of the LCC by 30 percent compared to intact LCC. This modulus degradation was selected based on the anticipated maximum shear strain of 0.07 percent in the LCC, which is based on our linear and nonlinear dynamic analyses under MCE loads using the program DeepSoil. We used the modulus degradation curves developed by Tiwani (2018) and selected a degraded modulus value close to the lower-bound curve at 0.07 percent shear strain. The resulting calculations show no reduction in the amount of ESALs using this degraded modulus; LCC with a reduced stiffness is still adequate to support the roadways.

We conclude that during a major earthquake, it is likely that the LCC will crack when subjected to the combined forces of surface waves and differential ground deformation. However, the likely consequences of LCC cracking from a major earthquake do not jeopardize the ability of the LCC to perform as intended to support the proposed roadway and underground utilities, and the cracking should be able to be addressed with post-earthquake maintenance. Accordingly, to perform as intended, it is not necessary that the LCC be free of cracking, but rather that the effects of cracking be taken into account in the design of the horizontal improvements at Mission Rock.

In conclusion, the anticipated seismic performance of the LCC is favorable, as summarized below:

- 28-day LCC compressive and shear strengths will be sufficient to resist cracking under earthquake cyclic shear stresses for the design-level earthquake.
- Minor or moderate cracking of the LCC is likely to occur and is allowable.
- Post-earthquake bearing capacity of the LCC is sufficient to support the streets, infrastructure, and other facilities.

- Post-earthquake pavement may require repairs similar those at other sites in San Francisco.

- Where the pavement is not damaged, the pavement performance is not jeopardized by LCC cracking.

- Utilities buried within the LCC should have acceptable performance as defined by the various owners of the utilities.

We appreciate the opportunity to assist you with this project, please call with any questions.

Sincerely,
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