BART Agreement Number: 6M8143 **Approval Date: 12/29/22**

Work Plan No. B.23-01 Silicon Valley Berryessa Extension Embankment Seismic Assessment

Scope:

This scope of work is presented in two parts: Base Scope and Optional Scope as defined below.

2.1 Base Scope

1a. Review relevant project-specific design criteria, specifications, geotechnical reports, record drawings, and construction submittals.

Our first task will be to review the project-specific documents, as listed above, provided by BART to gain an understanding of the project requirements as well as as-built conditions.

We will also perform a literature review of:

- Properties of LCC, including heat of hydration, specific heat, thermal conductivity, and static and dynamic moduli and strengths.
- HDPE geogrids such as Tensar UX1500, including modulus and strength changes as a function of temperature.
- MSE embankments constructed of LCC (e.g., Colton Crossing; San Bruno Grade Separation; Sound Transit Commuter Line Embankment; South Cove to South Station; Kamehameha Highway Guideway Design-Build, Honolulu, HI; Hunts Point Interstate Access Improvements - Sheridan Corridor, Bronx, NY; and Napoleon Street Bridge Replacement, San Francisco, CA) for comparison to the Project. This will include walls with other forms of LCC reinforcement since there are a limited number of LCC MSE walls restrained by geogrids.
- The results of numerical analyses of the BART Berryessa LSS MSE wall (e.g., Pradel & Tiwari, 2020: The use of MSE walls backfilled with Lightweight Cellular Concrete in soft ground

seismic areas), and Tiwari et al., 2020: Review of State of the Practice: Use of Lightweight Cellular Concrete (LCC) Materials in Geotechnical Applications.

- The results reported by Yuqiu Ye et al. (2022): "Pullout resistance of geogrid and steel reinforcement embedded in lightweight cellular concrete backfill," in Geotextiles and Geomembranes, https://doi.org/10.1016/j.geotexmem.2022.01.001.

- The results reported by Tiwari et al. (2017): "Mechanical Properties of Lightweight Cellular Concrete for Geotechnical Applications," in ASCE Journal of Materials in Civil Engineering, Volume 29 Issue 7. July.

Following the review of the documents above, a written summary of the findings presented in those documents related to the areas of interest for this scope of work, will be provided as a technical memorandum. This memorandum will be submitted to the project team for review and comment.

2a. Conduct a site visit to verify general conformance with record drawings and gather any other necessary information.

This site visit will be coordinated with BART staff. It will include a visual inspection of the existing embankments identified above from the base of the walls to observe any evidence of settlement, outward movement, panel cracking, panels shifting out of the plane, etc.

We would request permission from BART to take photographs (but these could be kept secure if requested by BART). Observations from this study will be summarized as part of the deliverable in Task 1a.

3a. Perform material property assessment of lightweight cellular concrete and geogrid.

Based on review of the documents listed above, an assessment of the stated material properties will be included in the Task 1a deliverable.

4a. Investigate the effect of heat on the geogrid, such as heat generated from concrete curing during construction. Evaluate the impact of heat on geogrid's design capacity and design life.

We understand that there have not been any temperature measurements of the LCC for the existing embankments identified above. However, typical values of Portland cement heat of hydration and specific heat are known as the thermal conductivity of LCC. We will review available data (e.g., from a Caltrans study 2002 [K Group of Ontario California] to consider duration and temperatures reached during mass placement of LCC) and perform some simple calculations to estimate maximum LCC temperature because of hydration.

We will perform a literature review of the effects that heat generated during hydration has on HDPE in general and on geogrids specifically.

Based on this information, we will provide an assessment of potential impacts. These potential impacts will be summarized and included in the Task 1a deliverable. In addition, we will make recommendations on how to model any of these possible effects on the short-term, long-term and seismic response of LCC MSE embankments.

5a. Based on the material properties determined above, perform analysis to determine the design demand and capacity of the embankment considering the material variability.

Utilizing all the information gathered from the previous tasks, we will develop recommended parameters for LCC and geogrids and perform a conventional design evaluation of the LCC MSE system. A list of our assumptions and proposed variabilities of material properties will be presented to BART for approval prior to performing the analysis.

Conventional MSE Design Evaluation

For the current study, we will perform design calculations using a conventional method developed for MSE walls at two locations in the embankments North and South of the Berryessa Station. We will recommend the critical locations and select the final two areas to be evaluated per coordination with BART. We will use the FHWA method (FHWA-NHI-10-024, Nov 2009), implemented in a Mathcad workbook. These calculations will use all of the material properties gathered in the previous tasks. We will evaluate short-term, long-term, and pseudo-seismic loading conditions. Based on our independent calculations, we will perform an independent evaluation of what was built to determine how it might be expected to perform in the short-term, long-term and under seismic loading conditions.

6a. Evaluate whether the as-built embankment satisfies the original Silicon Valley Berryessa Extension Project Design Criteria.

We will compare the performance predicted by the conventional analyses performed for the previous task with the various performance criteria defined by the original Silicon Valley Berryessa Extension Project Design Criteria.

7a. Further evaluation if the as-built condition does not meet the design requirements per the original Silicon Valley Berryessa Extension Project Design Criteria.

This task may be performed if authorized by BART as part of the Optional Scope described below in Section 2.2.

8a. Further evaluation if the as-built condition does not meet the life safety design requirements in an earthquake above.

This task may be performed if authorized by BART as part of the Optional Scope described below in Section 2.2.

9a. Prepare an assessment report to present the findings of this assessment. The information will contain the following main sections (at minimum):

a) Executive summary
b) Project description
c) Methodology
d) Assumptions
e) Summary of results
f) Recommendations to BART
g) Detailed calculations

2.2 Optional Scope

2b. Conduct a site visit to perform Vibration and other measurements at the embankment

This site survey will have been conducted under the Base Scope described above in Section 2.1.

This optional Task 2b may include placing surface vibration monitors at various locations along the top of the LCC and concrete topping slab. We further suggest leaving these overnight for about 24 hours to understand the level of vibrations that the train loading may cause in the underlying LCC embankment.

This optional task may also include performing a Multi-Channel Analysis of Surface Waves (MASW) or similar test program on top of the LCC MSE embankment to evaluate small-strain shear modulus values that will be relevant to our numerical modeling of seismic response to earthquake shaking.

This work will be coordinated with BART staff. We recognize that this work will likely need to be performed at night during non-revenue hours.

At this time, we are not proposing to perform any other surveying or detailed measurements. However, we may request this be added to our scope if the field observations suggest there may be value in this additional information. This will be discussed with BART at a future date during optional scope discussions.

Reports would be prepared by our geophysical sub-consultant and provided to BART.

HDR will work with BART to provide the Watchperson needed to escort NorCal Geophysics onto the track area, once to set up the vibration monitoring and perform the MASW work (up to one shift), and once to retrieve the vibration monitoring equipment (less than a couple of hours). We will coordinate with BART to provide this Watch person.

3b. Perform laboratory testing of LCC and geogrid to assess the material properties.

Under this Optional Scope and with insights gathered from the literature review described above under the Base Scope (Section 2.1 above), we propose to perform laboratory testing of LCC properties and geogrid-LCC interactions as described in the following bullets. We will perform this work in Wood's San Diego Materials Testing Lab (MTL).

We will procure all the testing materials and provide compensation to suppliers as needed to complete this work. We would strongly recommend this testing be performed on material that is as similar as possible to what was used for the Project construction: We will arrange with Cell-Crete to obtain the LCC required for the testing program; Cell-Crete is willing to provide 27 pcf LCC, in the quantities needed, at no cost to this study; we will coordinate to obtain the material at the location of another Cell-Crete LCC project.

We will discuss with BART the option to perform two phases of testing, with the second phase potentially being modified as appropriate based on findings from the first phase, as discussed below.

Initial Testing Program:

- Work with Cell-Crete to prepare several sets of 3-inch-diameter samples for confirmation of Unit Weight and Compressive Strength and several cylinders of 4 to 6 inches in diameter to test other parameters.
    - Other possible tests to perform include tensile strength (either with a splitting tension test or a flexural test), which may be relevant to modeling the

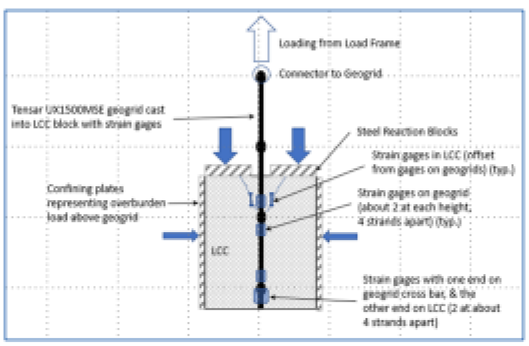
formation of tension cracks and failure wedges in the LCC embankment; and crushing resistant (e.g., possibly by punching a small cylinder into a sample of LCC), which may be relevant to modeling how LCC may overcome in front of each geogrid cross rib.

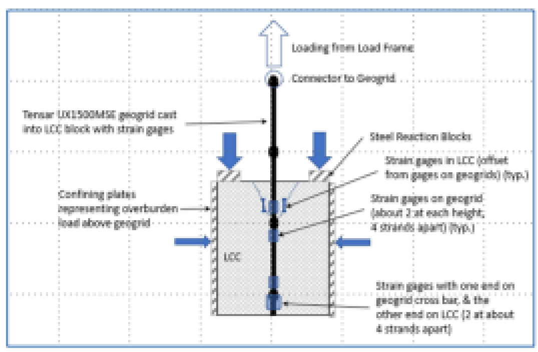
- Work with Cell-Crete to prepare about 2 to 4 LCC cylinders 6 inches in diameter with a length of geogrid cast vertically along the middle of the sample. We recommend a minimum of two pieces be tested in shear perpendicular to the plane of the geogrid. The final number can be determined when this optional scope is discussed at a future date.

- Work with Cell-Crete to prepare two boxes of LCC specially constructed to conform with the two sketches shown below. Each box would be assembled with a panel of geogrid placed vertically near the center of the box. The geogrid would be instrumented with strain measurement devices (vibrating wire strain gages, LVT strain gages, digital displacement instruments). The package would be brought to our San Diego MTL and tested by pulling on the geogrid to evaluate resistance against pullout, including load-deflection and ultimate pullout capacity (if this can be reached before failing the geogrid).

    - One box would be tested with the reaction blocks located close to the geogrid to preclude the wedges in front of the geogrid cross-rib from popping out. The other would be tested with the reaction blocks spaced further from the geogrid to allow these wedges to pop out if failure stresses (shear and tensile) in the LCC are reached.

    - Before constructing each box, shop drawings would be developed for review and approval by BART.





A simple test plan would be prepared at the beginning of this task and submitted to BART for review. After receiving BART's review comments, we would finalize the test plan and prepare for testing.

A simple Technical Memorandum would be prepared at the end of the Phase 2 laboratory program to describe the program, present the findings, and explain recommendations for the second round of testing.

Second Round Test Program

After reviewing the results of the initial testing phase, it will be evaluated whether there are lessons learned and whether it may be appropriate to perform additional box pullout tests, possibly with a modified test configuration. If so, a sequence similar to the initial testing program will be performed, developing a test plan and shop drawings for BART review and approval, sample collection, and testing.

A second simple Technical Memorandum would be prepared at the end of the laboratory program to describe the program and present the findings. This technical memorandum will be provided to the project team for review and comment before finalizing.

4b. Investigate the Perform numerical analysis to investigate the effect of heat on the geogrid and the effect of heat on the design capacity and design life of geogrid

A simplified evaluation of the effects of heat on the geogrid material properties will have been evaluated and described in the Base Scope above in Section 2.1.

If directed by BART during the Optional Scope, we could perform simple numerical modeling of how much the LCC is likely to have warmed following placement due to hydration.

Based on this information, we will evaluate how to model any potential effects on the short-term, long-term, or seismic response of LCC MSE embankments.

5b. Based on the material properties determined above, perform analysis to determine the design demand and capacity of the LCC MSE wall considering the material variability.

A conventional MSE analysis would be performed under the Base Scope described above under Section 2.1.

If directed by BART, during the Optional Scope, we could develop numerical models to evaluate local geogrid pullout potential and larger-scale LCC MSE wall and embankment performance, using parameters set in the previous tasks as the results of interface modeling performed for the current study.

Numerical Modeling

Numerical modeling may consist of the following components:

- Perform numerical modeling of the system's thermal behavior, accounting for the heat of hydration of the Portland cement component of the LCC and the LCC-specific heat and thermal conductivity-based parameters that are available in the literature.

  We tentatively propose performing this thermal modeling with Abaqus (discussed under the next bullet and also has thermal modeling capabilities).

  Based on the result of this analysis, we will evaluate the effect on the modulus (stiffness) and strength of the geogrids at various times after placement.

- Detailed 3-D modeling of stresses and strains for a block of geogrid-reinforced LCC similar to the configuration used in the pullout box laboratory tests. This testing will aim to calibrate the material properties and interface interaction behavior to confirm an understanding of the stresses and strains observed and inferred during the laboratory testing and assist predictions of as-built geogrid, LCC, or MSE panel displacements.

We propose to perform this modeling with 3-D Abaqus, a general Finite Element Method (FEM) platform that is widely recognized and widely used for complex and unusual configurations that do not yet have standard solutions, such as is the case for geogrid-reinforced LCC MSE embankments.

- Utilizing the results of the previous tasks and the detailed 3-D modeling that is part of this task, we will develop an equivalent 2-D representation of the LCC and geogrid for a 2-D complete cross-section of the LCC MSE Wall system. We will perform 2-D modeling of no more than four critical sections of the LCC MSE Wall system. This will include analyses of static short-term and long-term conditions during seismic loading.

    - fee proposal includes the pseudo-static analysis and response spectrum analysis, assuming that the time histories of design ground motions are not readily available. GSI plans to do limited (a few) time history runs using harmonic signals (unless time histories of design ground motions are readily available from BART) for developing strain-compatible properties for the response spectrum analysis. If BART's time histories of design ground motions are readily available, GSI will use the budget to perform a time history analysis instead.

    In the modeling, we will capture stresses and strains in the geogrids and LCC at various critical locations in the cross-section and overall displacements at multiple locations in the system. We do not expect the 3-D effects of the entire LCC MSE Wall to be significant and do not currently consider 3-D modeling of the whole wall necessary; however, we will provide recommendations for 3-D modeling if the 2-D results suggest a need for it.

6b. Evaluate whether the as-built embankment satisfies the original Silicon Valley Berryessa Extension Project Design Criteria.

If directed by BART to perform this Optional Scope, we will incorporate the new data gained by the optional tasks performed and compare the performance predicted in the previous task with the various performance criteria defined by the original Silicon Valley Berryessa Extension Project design criteria.

7b. If the as-built condition does not meet the design requirements per the original Silicon Valley Berryessa Extension Project Design Criteria:

a) Determine if the as-built condition meets the life safety requirements per the current industry standard. Consultant to propose industry standards to be used for the review.

b) Develop a monitoring/inspection program to monitor the LCC MSE wall's performance. Compare the anticipated performance with various design criteria, including the Caltrans SDC, as well as other as-yet-to-be-determined industry-standard design criteria. We expect this to include sources such as the California High-Speed Rail, Caltrain, AASHTO, FHWA, the California Building Code, etc.

Also, if any Silicon Valley Berryessa Extension Project Design Criteria are not satisfied, this task may include developing recommendations for a program to monitor and inspect the performance of the LCC MSE system. (Implementation of monitoring and inspection programs is not included in the currently proposed scope of services.)

8b. If the as-built condition does not meet the life safety design requirements in an earthquake above.

a) determine the seismic level that the existing design can meet the life safety requirements per the industry standard above.
b) Provide conceptual repair details or retrofit plan.

9b. Prepare an assessment report to present findings. The information will contain the following main sections (at minimum):

a) Executive summary
b) Project description
c) Methodology
d) Assumptions
e) Summary of results
f) Recommendations to BART
g) Detailed calculations

If tasks from the Optional Scope are performed, a second report would likely be needed to supplement the information prepared for the Base Scope. We would prepare a draft report for review and comment by BART. After receiving review comments, we would design a final report that includes responses to the review comments

Prime: HDR

Subconsultant	Amount	DBE (Y/N)	SBE (Y/N)
Wood	$ 430,043	N	N
GSI Environmental	$ 311,325	N	N
Nor Cal Geophysical	$ 5,232	N	N

Total Work Plan Value: $ 906,641