Alameda Unified School District Board of Education
Alameda Unified School District
2060 Challenger Drive
Alameda, California 94501

May 17, 2017

RE: Donald Lum Elementary School Liquefaction Settlement

AUSD Board,

ZFA is providing the following additional commentary, in conjunction with our letter dated April 24, 2017, to clarify our conclusion that the existing classroom, multi-use, and administration buildings at Donald Lum Elementary School have a high potential for partial or global collapse during a design-level seismic event due to foundation failures as a result of expected large differential settlements, and that retrofitting the existing structures is not practical.

This is not a conclusion that we come to lightly. ZFA has been involved in a substantial amount of school projects over its 43-year history, including the evaluation of many existing school buildings. During these projects, we have only encountered similar soil hazards with incompatible foundations at two other campuses, which also included buildings of similar construction type. In both of these cases, the districts, in conjunction with our recommendations, demolished the original structures and built more resilient structures on the same site to reduce the risk to students and staff.

As the industry's knowledge of earthquakes, building performance and soil-structure interaction has increased over the last half century, certain building types and site conditions have been identified as posing significantly higher hazard than other construction of a similar vintage. Significant differential settlement due to liquefiable soil in high seismic regions without an adequate foundation system is one of these conditions.

The buildings at Donald Lum Elementary School were built at a time when liquefaction was not well studied, identified, or accounted for in building designs. Therefore, the foundations at Donald Lum Elementary School were not designed to withstand soil failure or resist the large vertical ground movements which are now expected during a seismic event at this site.

The foundations for the earliest buildings, built in 1959-1964, are shallow, relatively narrow footings with a relatively small amount of steel reinforcing. A typical footing section can be seen in Figure 1. In this example, the footing is 24 inches deep and 18 inches wide with one reinforcing bar in the top and another in the bottom of the footing. The later building, built in 1974, is slightly more robust with more footing reinforcement. These footings were designed to support the building weight directly on the soil below. They are not designed for, or adequate to transfer building weight over significant distances to bridge across soil that has lost its strength due to liquefaction. This was, and is, standard practice for building sites with good or average soil conditions. Even modern well designed buildings generally do not have adequate foundations to withstand the 7” of expected differential settlement expected at Donald Lum Elementary School unless they were specifically designed for it.

When seismic-induced settlements in the range of 3 to 4 inches are expected, foundations can generally be designed with concrete grade beams to span across this disruption in soil support, typically 15 to 25 feet. In these conditions, the foundations become significantly larger as compared to buildings with good soil conditions. As long as the foundation can structurally support the building weight, including the effects of the earthquake, then significant foundation movement can be avoided or reduced.

Where settlements are similar or slightly greater, another foundation system that can be used is a mat slab. This system uses a thick solid slab that supports the building like a raft. For school buildings, the slab thickness often ranges between 12 and 30 inches depending on actual forces and the building configuration. In some cases, thickened elements are also required. In our opinion, this is not the best solution for the subject site given the significant expected ground movement. Furthermore, this is an impractical solution under an existing building.

The most appropriate foundation system for a site with expected settlement in the range of this site is a deep foundation system. This system typically consists of a structural slab supported on concrete grade beams which are supported on steel or concrete piers or piles that would be, in this case, approximately 70 feet deep. This system supports the weight of the building below the layers of soil which can liquefy. It would be impractical to provide 70 foot foundation elements and new foundation concrete within the building footprint.

We evaluated the existing footings in a couple of typical locations, using ASCE 41-13 Seismic Evaluation and Retrofit of Existing Structures, to span over a length of 25 feet which is similar to other designs of new buildings on liquefiable soil and in conjunction with the Geotechnical Engineer. Based on our analysis, the footings do not have the strength to span this distance and will likely experience displacement matching the liquefaction settlement of the soil below, leading to partial or global collapse of the structure above.

While we believe a stiffened grid foundation to resist the large settlements expected at Donald Lum Elementary School is not the appropriate system for this site, we did calculate what a potential required size might be. Figure 2 indicates a preliminary foundation size for a portion of the building based on a 25-foot unsupported footing length. While this solution is feasible from a structural perspective, it would be difficult or impossible to construct under an existing structure. If pursued, this foundation system would be required to be installed under all bearing walls and in a regularly spaced grid across the building.

Buildings of the type of construction at Donald Lum Elementary School generally behave in a ductile manner during an earthquake experiencing significant lateral movement during shaking and then return to its pre-earthquake shape with relatively minor structural damage. In the case of the Donald Lum Elementary School buildings, this horizontal movement will be occurring when the structure could experience very significant vertical differential settlement of up to 7”. The vertical movement will cause additional stress on connections not accounted for in the original design. As noted above, one cannot predict exactly where liquefaction will manifest itself within the building footprint. The specific reasons for any one area to have the potential for collapse are not significantly influenced by the shape of the building but by the details of the connections of the elements. As an example, there are areas where the roof rafters frame into the side of a major wood roof beam, settlements of one end the roof rafters could cause the framing to pull away from the beam and create a situation where partial collapse could occur.

This connection only becomes potentially hazardous because of the potential settlement of the building.

Finally, while non-structural element damage would not trigger a need to vacate a campus, there will be significant risk of injury due to many hazards. In areas where the footing becomes severely deformed, windows may shatter and doors will become in-operable. There are skylights in many spaces, as well as other non-structural elements and it is likely that the additional movement could cause these elements to break or collapse. These movements will likely cause rupture of gas, water and sewer lines in areas of abrupt change. As ZFA saw in the Napa earthquake, damage to and failure of nonstructural elements can be very extensive. These would only be expected to be magnified as the structural elements become distressed during the building settlement.

ZFA was one of two structural engineering firms to be hired by The Division of the State Architect (DSA) to assist in developing a procedure to allow school districts to access seismic mitigation funding as provided by Proposition 1D. The purpose of this program was to provide funding to help districts retrofit buildings that have an unacceptable risk of partial collapse. As part of this procedure, known as 08-03, liquefaction settlement could qualify the school campus for 50% replacement cost. Under this program, DSA and/or CGS will review and likely concur that the building(s) have “a high potential of local or global collapse.” This process takes several months for approval and any funding for a campus replacement would not occur until the replacement campus was approved by DSA.

A Field Act-compliant building designed and built today, based on current engineering knowledge, would be expected to maintain life safety and would not be expected to experience structural collapse in a seismic event of the level expected on the Hayward Fault. In its current state, Donald Lum Elementary School due to the expected soil movement, contains a high potential of partial or global collapse. In our professional opinion, since there does not appear to be a way to cost-effectively mitigate the hazard, the School Board should work to develop a plan to locate alternate facilities for the students and staff.

Should you have questions, please contact the undersigned.

Regards,

Chris Warner

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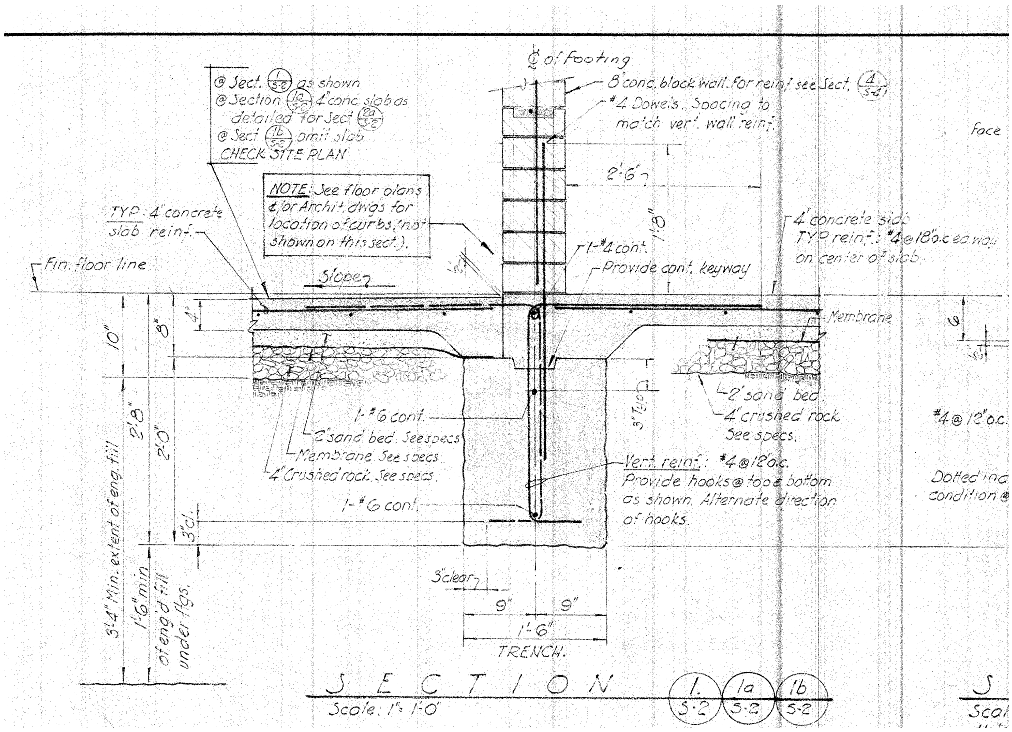

Figure 1 - Existing Footing

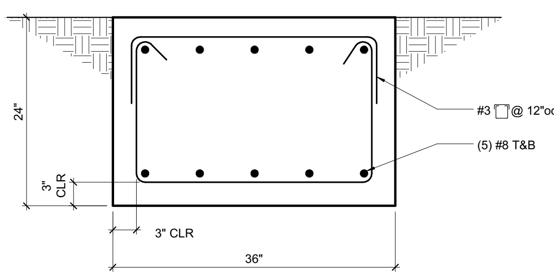

Figure 2 - Typical New Footing