SECTION 3.0 DISCUSSION AND RECOMMENDATIONS

Based on the results from our field exploration, the project site is generally underlain by pavement structures consisting of about 3 and 5 inches of asphaltic concrete and about 3 and 6 inches of base material overlying alluvial soils and basalt rock formation extending down to the maximum depth explored of about 14.7 feet below the existing ground surface. The alluvial soils were encountered to depths of about 11 and 14.5 feet below the existing ground surface and generally consisted of loose to medium dense silty sand and stiff to very stiff sandy silt and sandy clay.

Hard basalt rock formation was encountered underlying the alluvial soils and extended down to the maximum depth explored of about 14.7 feet below the existing ground surface. We did not encounter groundwater in the borings at the time of our field exploration. However, it should be noted that groundwater levels are subject to change due to rainfall, time of year, seasonal precipitation, surface water runoff, and other factors.

We anticipate the foundation soils beneath the new fueling station concrete pad/mat foundation may consist of the loose to medium dense silty sand encountered in our borings at the project site. To reduce the potential for differential settlement from non-uniform bearing conditions, we recommend placing a minimum 12-inch thick layer of aggregate subbase material below the concrete pad/mat foundations to provide a firm and unyielding bearing layer. The aggregate subbase material should be compacted to a minimum of 95 percent relative compaction.

Based on our engineering analyses and the subsurface condition encountered, we recommend the new wash rack pavements consist of Portland cement concrete at least 6 inches thick overlying a minimum of 12 inches of aggregate subbase material. The aggregate subbase material should also be compacted to a minimum of 95 percent relative compaction. Aggregate subbase materials should consist of crushed basaltic aggregates and should meet the requirements of Section 703.17 of the State of Hawaii, Standard Specifications for Road and Bridge Construction (2005).

Detailed discussion of these items and our geotechnical recommendations for design of fueling station foundations, site grading, pavements, and other geotechnical aspects of the project are further discussed in the following sections.

3.1 FUELING STATION FOUNDATIONS

Based on the subsurface conditions encountered at the project site, we believe a concrete pad/mat foundation may be used to support the new fueling station. We anticipate the foundation soils may consist of the loose to medium dense silty sand encountered in our borings at the project site. To reduce the potential for differential settlement from non-uniform bearing conditions, we recommend placing a minimum 12-inch thick layer of aggregate subbase material below the concrete pad/mat foundations to provide a firm and unyielding bearing layer. The aggregate subbase material should be compacted to a minimum of 95 percent relative compaction.

The over-excavated concrete pad/mat foundation subgrades (beneath the 12 inches of aggregate subbase material) should be scarified to a depth of 10 inches, moisture-conditioned to above the optimum moisture content, and recompacted to at least 95 percent relative compaction. Soft and/or loose materials encountered at the bottom of the concrete pad/mat foundation excavations should be over-excavated to expose the underlying firm materials. The over-excavation should be backfilled with aggregate subbase material compacted to a minimum of 95 percent relative compaction.

Based on our field exploration and engineering analyses, an allowable bearing pressure of up to 2,500 pounds per square foot (psf) may be used for design of the concrete pad/mat foundation bearing on the 12-inch thick layer of aggregate subbase material. This bearing value is for dead–plus-live loads and may be increased by one-third (⅓) for transient loads, such as those caused by wind or seismic forces. The bottom of the concrete pad/mat foundation should be embedded a minimum of 24 inches below the lowest adjacent finished grade.

The allowable bearing pressure provided above is a net value; therefore, the weight of the concrete pad/mat foundation may be discounted. In general, we recommend using a modulus of subgrade reaction of about 35 pounds per square inch per inch of deflection (pci) in the design of the concrete pad/mat foundation under long-term loading conditions. For transient loads, such as wind and/or seismic loading, the modulus of subgrade reaction may be increased to 60 pci in the design.

Based on our engineering analyses, we believe that total foundation settlements on the order of about 1 inch and differential settlements between the center and the edge of the concrete pad/mat to be on the order of about 0.5 inch or less are anticipated for the fueling station supported on the proposed concrete pad/mat foundation. We believe that a significant portion of the estimated settlements is elastic and should occur as the loads are applied.

Lateral loads acting on the structures may be resisted by friction developed between the bottom of the concrete pad/mat foundation and the bearing soils and by passive earth pressure acting against the near-vertical faces of the foundation system. A coefficient of friction of 0.4 may be used to evaluate the sliding resistance between the bottom of the concrete pad/mat foundation and the 12-inch thick layer of aggregate subbase material. Resistance due to passive earth pressure may be estimated using an equivalent fluid pressure of 300 pounds per square foot per foot of depth (pcf). This assumes that the backfill around the concrete pad/mat foundation is well-compacted. Unless covered by pavements or slabs, the passive resistance in the upper 12 inches of soil should be neglected.

Resistance to uplift loads may be mobilized by the dead weight of the structure and the concrete pad/mat foundation. In addition, the weight of the soil above the mat foundation may be used to resist uplift loads. Contribution of dead weight from the soil above the mat foundation may be estimated using a unit weight of 110 pounds per cubic foot (pcf).

A Kokua Geotech LLC representative should observe the concrete pad/mat foundation excavations prior to placement of the aggregate subbase materials, reinforcing steel, and concrete to confirm the foundation bearing conditions.

3.2 SOLAR CARPORT FOUNDATIONS

We understand solar carport structures are being considered for some of the parking areas at the project site. Based on preliminary information provided by the project structural engineer, we understand maximum loads for a typical interior column are estimated to be about 6 kips for dead load and 8 kips for the roof live load. We understand maximum shear and overturning moments have not been determined at this preliminary design phase of the project. Based on our experience with similar solar carport structures, we anticipate that the shear and overturning moment at the base of the structure column will govern the design of the drilled shaft foundation.

In order to develop the anticipated bearing and lateral load resistances, we recommend supporting the new solar carport structures on a foundation system consisting of cast-in-place concrete drilled shaft foundations. In general, drilled shaft foundations are constructed by drilling a hole down into the bearing strata, placing reinforcing steel, and then pumping high slump concrete to fill up the hole. The result is a cast-in-place concrete drilled shaft for foundation support.

Based on the anticipated structural load demands and the subsoil conditions encountered at the project site, we envision installing drilled shaft foundations with minimum diameters ranging from 18 to 24 inches and embedment lengths ranging from about 10 to 20 feet below the design finished grade to support the new solar carport structures planned for the project. We envision the drilled shaft foundations would derive vertical support primarily from skin friction between the drilled shaft and the surrounding materials and some end bearing on the very stiff clayey soils and/or basalt rock formation encountered in our borings drilled at the project site.

Lateral loads imposed on the drilled shaft foundations may be resisted by a combination of the passive pressure acting against the near-vertical faces of the foundation caps, if utilized, and the lateral load capacity of the drilled shaft foundation. Passive earth pressure against the near-vertical faces of the foundation caps may be estimated using an equivalent fluid pressure of 350 pounds per cubic foot (pcf).

Lateral load resistance of drilled shafts is a function of the stiffness of the surrounding soil, the stiffness of the drilled shaft, allowable deflection at the top of the drilled shaft, and the induced moment in the drilled shaft. Once the maximum shear and overturning moment loading are determined for the structures, lateral load analyses will be performed using the program *LPILE*, which is a special-purpose computer program that analyzes a deep foundation under lateral loading using the “p-y” method. This method uses non-linear “p-y” curves to represent soil moduli.

The above drilled shaft foundation recommendations are for preliminary design purposes only. Final drilled shaft diameters and depths must be approved by Kokua Geotech LLC. In addition, the construction plans and specifications for the project should be forwarded to us for review to determine whether the recommendations contained in this report are adequately reflected in those documents. If this review is not made, Kokua Geotech LLC cannot assume responsibility for misinterpretation of our recommendations.

3.3 SITE GRADING

A grading plan was not provided at the time this report was prepared. We envision site grading for the project to generally consist of cuts and fills associated with foundation construction, new pavements, and infrastructure installation at the project site. Site grading items that are addressed in the subsequent subsections include the following:

1. Site and Subgrade Preparation
2. Excavations
3. Fill/Backfill Materials
4. Fill/Backfill Compaction Requirements

A Kokua Geotech LLC representative should monitor site grading operations to observe whether undesirable materials are encountered during the excavation and subgrade preparation process, and to confirm whether the exposed soil conditions are similar to those assumed in this report.

3.3.1 SITE AND SUBGRADE PREPARATION

At the on-set of earthwork, areas within the contract grading limits should be cleared thoroughly. Surface vegetation, debris, deleterious materials, existing structures and pavements to be demolished, and other unsuitable materials should be removed and disposed of properly off-site.

After clearing and demolition, areas at grade or areas designated to receive fills should be scarified to a depth of about 10 inches, moisture-conditioned to above the optimum moisture content, and compacted to a minimum of 90 percent relative compaction. Relative compaction refers to the in-place dry density of soil expressed as a percentage of the maximum dry density as determined by ASTM D1557. Optimum moisture is the water content (percentage by weight) corresponding to the maximum dry density.

Soft and yielding areas encountered during clearing and subgrade preparation should be over-excavated to expose firm material, and the resulting excavation should be backfilled with well-compacted general fill. The excavated soft soils should be properly disposed of off-site and/or used in landscape areas, where appropriate.

3.3.2 EXCAVATIONS

All excavations should be made in accordance with applicable Occupational Safety and Health Administration (OSHA) and state regulations. The contractor should determine the method and equipment to be used for the excavations, subject to practical limits and safety considerations. In addition, the excavations should comply with the applicable federal, state, and local safety requirements. The contractor should be responsible for trench shoring design and installation.

Based on the information provided, we envision excavations for the project will generally consist of excavations for foundation construction and utility installation. Based on our borings, these excavations may encounter loose to medium dense sandy soils and stiff to very stiff sandy silt/clay. In addition, boulders and hard basalt rock formation may be encountered in the planned excavations.

It is anticipated that most of the material may be excavated with normal heavy excavation equipment. However, deep excavations and excavations encountering boulders and hard basalt rock formation may require the use of hoerams. Contractors should be encouraged to examine the site conditions and the subsurface data to make their own reasonable and prudent interpretation.

3.3.3 FILL/BACKFILL MATERIALS

In general, the excavated on-site soils may be re-used as a source of general fill provided they are free of vegetation, deleterious materials, and rock fragments greater than 3 inches in maximum dimension.

Imported fill materials, if required, should consist of non-expansive structural fill material, such as crushed coral or basalt. The structural fill should be well-graded from coarse to fine with particles no larger than 3 inches in largest dimension. The material should have a CBR value of 20 or higher and a swell potential of 1 percent or less when tested in accordance with ASTM D1883. The material should also contain between 10 and 30 percent particles passing the No. 200 sieve.

Aggregate base course and aggregate subbase materials should consist of crushed basaltic aggregates and should meet the requirements of Sections 703.06 and 703.17, respectively, of the State of Hawaii, Standard Specifications for Road and Bridge Construction (2005). Kokua Geotech LLC should test imported fill materials for conformance with these recommendations prior to delivery to the project site for the intended use.

3.3.4 FILL/BACKFILL COMPACTION REQUIREMENTS

General fill and structural fill materials should be moisture-conditioned to above the optimum moisture content, placed in level lifts not exceeding 8 inches in loose thickness, and compacted to a minimum of 90 percent relative compaction. Fills and backfills within 2 feet of the pavement grade elevation should be compacted to a minimum of 95 percent relative compaction.

Aggregate base and subbase course materials should be placed in level lifts of about 8 inches in loose thickness, moisture-conditioned to above the optimum moisture, and compacted to at least 95 percent relative compaction.

Relative compaction refers to the in-place dry density of soil expressed as a percentage of the maximum dry density of the same soil determined in accordance with ASTM D1557. Optimum moisture is the water content (percentage by dry weight) corresponding to the maximum dry density.

Site grading operations should be observed by a representative from Kokua Geotech LLC. It is important that a representative from our office observe the site grading operations to evaluate whether undesirable materials are encountered during the subgrade preparation process and whether the exposed soil/rock conditions are similar to those encountered in our field exploration.

3.4 FIELD PERMEABILITY TESTING

One field permeability test was conducted in the borehole of Boring No. 2 at a depth of about 10 feet below the existing ground surface to evaluate the infiltration characteristics of the subsurface materials encountered at the proposed drywell location. A falling head permeability test was performed in the drilled boring to determine the average hydraulic conductivity of the underlying subsurface materials. In general, clear water was introduced into the boring and the drop of the water level in the boring was measured along with time.

The field data for the falling head test was analyzed using formulae shown in "Seepage, Drainage and Flow Nets, 3rd Edition", Cedergren, 1989. Based on the falling head field permeability test results, the estimated hydraulic conductivity (k) at the test location is summarized in the following table. The results of our field permeability test is presented in Appendix C.

FIELD PERMEABILITY TEST RESULTS			
Test Location	**Testing Depth** (feet)	**Estimated Hydraulic Conductivity** (feet/minute)	(centimeters/second)
B-2	0 – 9	8.9×10^{-4}	4.5×10^{-4}

3.5 PAVEMENT DESIGN

We understand new asphaltic concrete (flexible) and Portland cement concrete (rigid) pavements are planned for portions of the parking and access road areas and the new wash rack. In general, we anticipate vehicle loading for the project will consist primarily of passenger vehicles and light trucks with some heavy trucks.

Detailed traffic projections for the new pavements were not provided at the time this report was prepared. Therefore, the following design parameters were assumed for preliminary pavement design purposes. In addition, we assume the pavement subgrade soils will consist of the alluvial soils encountered during our field exploration.

DESIGN TRAFFIC PARAMETERS	
Design Average Daily Traffic (Vehicles Per Day Per Direction)	500
Traffic Volume Growth Rate	2.0% each year
Design Period	30 Years
Total ESAL in 30 Years	1,000,000

Based on the above assumptions, we recommend using the following pavement design sections for preliminary design purposes:

Flexible Pavements for Parking Areas
4.0-Inch Asphaltic Concrete
8.0-Inch Aggregate Base Course (95 Percent Relative Compaction)
12.0-Inch Total Pavement Thickness on Moist Compacted Subgrade

Rigid Pavements
6.0-Inch Asphaltic Concrete
12.0-Inch Aggregate Subbase Course (95 Percent Relative Compaction)
18.0-Inch Total Pavement Thickness on Moist Compacted Subgrade

The pavement subgrade soils should be scarified to a minimum depth of about 10 inches, moisture-conditioned to above the optimum moisture content, and compacted to not less than 95 percent relative compaction. The subgrade soils should be thoroughly moistened and kept moist until covered by the pavement structural section.

Aggregate base and subbase course materials should be compacted to at least 95 percent relative compaction and meet the material requirements meet the requirements of the State of Hawaii, Standard Specifications for Road and Bridge Construction (2005). CBR and field density tests should be performed on the actual materials used during construction to confirm the adequacy of the above section. The recommended section also assumes that adequate drainage will be provided for the paved areas.

As an additional check for stability and uniform compaction, we recommend proof-rolling the pavement subgrade prior to placing the aggregate base/subbase course materials using a pneumatic tired vehicle with a gross vehicle weight of at least 30,000 pounds, such as a fully-loaded water truck. The equipment used for proof-rolling should be operated at a speed of about 300 feet per minute and make at least two passes over each area designated for proof-rolling. Proof-rolling should also be performed on successive lifts of aggregate base/subbase course materials. Areas with excessive rutting and/or pumping should be over excavated to expose firm material, and the resulting excavation should be backfilled with well-compacted aggregate base course material.

Paved areas should be sloped, and drainage gradients should be maintained to carry the surface water off the site. Surface water ponding should not be allowed on the site during or after construction. Where concrete curbs are used to isolate landscaping in or adjacent to the pavement areas, we recommend that the curbs be extended a minimum of 2 inches into the soils below the subgrade to reduce the potential for appreciable landscape water migration into the pavement section.

3.6 UTILITY TRENCHES

We envision new underground utilities may be required for the project. As discussed above, all excavations should be made in accordance with applicable Occupational Safety and Health Administration (OSHA) and state regulations. The contractor should determine the method and equipment to be used for utility trench excavation, subject to practical limits and safety considerations. In addition, the trench excavations should comply with the applicable federal, state, and local safety requirements. The contractor should be responsible for trench shoring design and installation.

In general, we recommend providing granular bedding consisting of 6 inches of open-graded gravel, such as No. 3 Fine gravel (ASTM C33, No. 67 gradation), under the pipes for uniform support. In addition, open-graded gravel (ASTM C33, No. 67 gradation) should also be used for the initial trench backfill up to about 12 inches above the pipes to provide adequate support around the pipes. It is critical to use a free-draining material, such as open-graded gravel, to reduce the potential for formation of voids below the haunches of pipes and to provide adequate support for the sides of the pipes. Improper trench backfill could result in backfill settlement and pipe damage.

Trench backfill material above the open-graded gravel may consist of general fill materials (on-site soils) or structural fill material. The backfill should be placed in maximum 8-inch level loose lifts and mechanically compacted to no less than 90 percent relative compaction to reduce the potential for appreciable future ground subsidence. The upper 2 feet below the finished grade in areas subjected to vehicular traffic should be compacted to a minimum of 95 percent relative compaction.

3.7 SITE DRAINAGE CONSIDERATIONS

The drainage condition around the building structures is critical to maintaining proper foundation performance because ponded water could cause subsurface soil saturation and subsequent heaving or loss of strength. Finished grades outside the new structures should be sloped to shed water away from the slab and foundations and to reduce the potential for ponding around the structures.

Drainage systems and finished grades for the project site should be designed by a Licensed Civil Engineer so that surface runoff is directed away from the building and other related structures. Drainage swales should be provided as soon as possible and should be maintained to drain surface water runoff away from the slab and foundations. The foundation excavations should be properly backfilled against the walls or slab edges immediately after setting of the concrete to reduce the potential for excessive water infiltration into the subsurface.

3.8 DESIGN REVIEW AND CONSTRUCTION OBSERVATION SERVICES

The construction plans and specifications for the project should be forwarded to us for review to determine whether the recommendations contained in this report are adequately reflected in those documents. If this review is not made, Kokua Geotech LLC cannot assume responsibility for misinterpretation of our recommendations.

Kokua Geotech LLC should also be retained to monitor the foundation excavations, site and subgrade preparation, fill and backfill placement, proof-rolling of pavement subgrade, aggregate base/subbase course placement and other aspects of earthwork construction to determine whether the recommendations of this report are followed. The recommendations presented herein are contingent upon such observations. If the actual exposed subsurface soil conditions encountered during construction differ from those assumed or considered in this report, Kokua Geotech LLC should be contacted to review and/or revise the geotechnical recommendations presented herein.

END OF DISCUSSION AND RECOMMENDATIONS