V. CONCLUSIONS AND RECOMMENDATIONS

Based on the data obtained in the field and laboratory testing programs, the following conclusions and recommendations for design and construction of the proposed building are presented.

A. DESIGN RECOMMENDATIONS

1. **Foundation Alternatives.** Due to the presence of variable consistency miscellaneous fill soils underlain by a thick layer of soft, compressible soils, the site is generally not considered suitable for supporting the proposed structure on a spread foundation system and slab-on-grade. While a structural concrete mat might be suitable for controlling differential settlement across the structure, a mat foundation is not considered likely to be a cost-effective foundation alternative at this site. Drilled shafts (caissons) could provide a suitable support system for the structure, but would require offsite disposal of a significant quantity of soil cuttings. Therefore, it is Duffield Associates' recommendation that a steel pile foundation system be utilized for the project. The remaining recommendations in this report assume that building foundations will be supported by a driven steel pile system. Additional recommendations regarding other foundation types can be provided upon request.

2. **Driven Pile Foundation System.** Several steel pile sections could be considered feasible for this project. Based on the project team recommendation, a steel pipe is considered appropriate for this project, an is the focus of the remainder of this report. Recommendations for design and construction with other pile types can be provided, upon request.

A driven, concrete-filled closed-end steel pipe pile foundation system is recommended for the support of the proposed foundations and slab. Analysis indicates that nominal 12-inch diameter steel pipe pile with ½ inch thick walls, driven to depths of approximately 60 feet below the proposed slab elevation, should be capable of developing an allowable design capacity of 60 tons per pile (ultimate capacity of 126 tons with a factor of safety of 2 and a negative skin friction of 6 tons). Actual pile lengths required may vary, based on driving conditions encountered in the field (see Recommendations B.1, B.2 and B.3). In all cases, piles should be driven to a depth of at least 50 feet below the proposed floor slab.

3. **Building Slab.** The building floor slab should be fully supported by the building pile foundation system. A free draining subbase, consisting of at least 6 inches of poorly graded aggregate, such as AASTHO SP-57 stone, should be provided beneath all floor slabs. A vapor barrier is also recommended beneath the floor slab.
4. **Vented Slab Subgrade.** A venting system is recommended to remove potential gases that could accumulate from the below grade decomposition of organic materials. A typical passive venting system consists of a perforated pipe (PVC or flexible polyethylene) in AASHTO SP-57 stone bedding at approximate 50-foot intervals along the length of the building, vented at grade. Building slab isolation and expansion joint fills should be designed to restrict the migration of vapors into the building.

5. **Bulk Site Grading.** Net fills of up to 5 feet are proposed in the southern portion of the site. Assuming that typical soil fill materials are used, the weight of this fill material will result in settlement of the underlying soft, compressible soils over time. A total settlement of up to 2 inches is considered possible in areas with 5 foot thick fills. While this settlement should not have a detrimental effect on the building, since the slab and foundations will be supported on piles founded on the underlying dense soils, it may impact other site features, such as sidewalks, exterior slabs or pavement areas constructed above these fill areas, as well as utilities entering the building.

In fill areas where settlement sensitive site features are proposed or where differential settlement between the feature and building would not be desirable, the use of lightweight fill materials such as geofoam or bottom ash should be considered. Placement of fill materials as far ahead of the finished construction as possible would reduce the amount of post-construction settlement that will occur, but settlement of these areas will likely occur for several years following placement of the fill material. Surcharge of the fill areas could also be considered to accelerate the settlement period. However, this may not be feasible due to the limited space at the work site.

Utilities entering the southern portion of the building in the proposed fill areas will also experience settlement due to compression of the underlying soils. Flexible connections are recommended to accommodate differential settlement of the utility relative to the pile-supported structure. Where possible, it is recommended that utilities enter the northern portion of the building area where no significant amounts of fill are proposed and the resulting risk of settlement is less.

6. **Soil Parameters.** The following soil parameters for lateral earth loads and braced excavation design are recommended:
7. Retaining Wall Design. Backfill pressures on "unyielding" retaining walls restrained from rotation at the top should be analyzed using the "at rest" earth pressure coefficient, $K_o$. The "active" and "passive" earth pressure coefficients, $K_a$ and $K_p$, respectively, should be utilized for the design of "yielding" retaining walls such as cantilevered walls. All retaining walls (including below grade portions of the building) should be provided with granular backfill materials and a drainage system and/or weep holes to relieve hydrostatic pressures on the walls.

8. Pavement Design. Based on anticipated traffic loading consisting primarily of passenger vehicles in the proposed parking areas (with limited access to trash collection vehicles and other truck traffic) and the subgrade conditions encountered, the following minimum pavement section is recommended.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/2 inches</td>
<td>Bituminous Concrete Wearing Course, Type C</td>
</tr>
<tr>
<td>2-1/2 inches</td>
<td>Bituminous Concrete Binder Course, Type B</td>
</tr>
<tr>
<td>10 inches</td>
<td>Graded Aggregate Base Course, Type A Geotextile Fabric, Geotex 315 or equivalent</td>
</tr>
<tr>
<td>14 inches</td>
<td>Total Depth</td>
</tr>
</tbody>
</table>

All pavement construction and materials should conform to the Delaware Department of Transportation Standard Specifications for Roadway and Bridge Construction, dated August 2001 and as subsequently revised. Additionally, underdrains are recommended to facilitate drainage within the pavement base course particularly at topographic low areas, such as the base of slopes. A typical underdrain system consists of 4 inch perforated polyethylene pipe (e.g., ADS or equivalent) in an AASHTO SP-57 stone bedding. The stone bedding should be at least 12 inches wide and should be wrapped in a geotextile fabric (e.g., Geotex 801 or equivalent).
9. Existing Utilities. Several utilities, including storm sewer, sanitary sewer, and electric for site lighting, were delineated within, or adjacent to, the proposed building area. While the proposed building is pile supported and should not impose additional loads on the pipe, it is generally not recommended to leave active utilities in place beneath a structure as they would be difficult to access for future maintenance or replacement without disturbance to the building. It is recommended that these utilities be removed and relocated outside of the building area. The resulting excavations should be backfilled with structural fill, placed, and compacted in accordance with the recommendations of this report. Alternatively, where they would not interfere with pile installation, the existing pipe could be abandoned, left in place, and grouted “full” throughout its length.

10. Seismic Design Parameters. Based on subsurface conditions encountered during the field exploration at the site, an “S3” soil profile type for design of seismic conditions, as defined by Table 1612.3.1 of the 1996 BOCA Building Code, is recommended, or Site Class “F”, as defined by Table 1615.1.1 of the 2000 International Building Code, is recommended.

11. Site Grading. Site grading should be designed to provide positive drainage away from the proposed structure. Because the shallow site soils are considered moisture sensitive, positive site drainage should be maintained on the exposed building and pavement areas throughout the construction activities.

12. Assumptions. The recommendations of this report were made based on the design information provided and Duffield Associates’ understanding of the proposed building design at the time of this evaluation. The project team should compare the final loading and grading conditions to those used in this analysis. If design loading and grading conditions vary from those used herein, Duffield Associates should be contacted. Additionally, Duffield Associates requests the opportunity to review the completed design drawings and technical specifications for consistency with the intent of this report.

B. CONSTRUCTION RECOMMENDATIONS

1. Handling of Miscellaneous Fill Soils. The miscellaneous fill encountered within the building site contained material (brick, concrete, glass, ash, cinders, slag, metal, etc.) which is classified as Regulated Solid Waste by the Delaware Department of Natural Resources and Environmental Control (DNREC). These materials are not considered suitable for on-site structural fill and may present health and safety concerns during construction. Accordingly, materials excavated during site development may require disposal at a permitted landfill or permitted recycling facility. Environmental characterization has been performed by others. Due to potential health and safety concerns to workers during building construction, the contractor should
develop a site specific health and safety plan considering the subsurface conditions encountered during this evaluation and the findings and recommendations of the environmental evaluation by others.

2. **Pile Driving Criteria.** The contract documents should include provisions for the contractor to submit a wave equation analysis for the proposed piles in order to establish driving criteria for an ultimate pile capacity of 126 tons per pile. The wave equation analysis should be performed and sealed by a professional engineer registered in the State of Delaware. A minimum hammer size of 15,000 ft-lb is recommended. The submittal should include an analysis for a 60 foot long pile with 35% skin friction at 100% embedment. A triangular distribution of frictional resistance acting along the portion of the pile below 30 feet from ground surface should be assumed for this analysis.

3. **Probe Piles.** Prior to driving of production piles, it is recommended that at least 8 “probe” piles be initially driven at various foundation locations throughout the site. The purpose of the probe piles is to obtain additional information regarding the driving conditions at the site and to provide a more accurate indication of the required pile lengths. The performance of a “Quick Load Test” on one of the probe piles, in accordance with ASTM D1143 and as required by the 2000 International Building Code, shall be performed prior to the start of the production driving.

4. **Testing During Pile Installation.** A Pile Driving Analyzer (PDA) should be used during driving to verify the capacity of probe piles driven prior to the installation of the production piles. The PDA consists of a strain gauge and accelerometer, which are attached to the top of the pile during driving. The parameters that are measured by the PDA permit for an interpretation of the frictional and bearing resistance developed by a pile as a means of verifying the pile’s capacity, as well as verifying the performance of the hammer and driving stresses during the probe pile program. The performance of the PDA testing should be provided and interpreted by a qualified geotechnical engineer retained by the Owner. The PDA can also be utilized later during production driving (if necessary) to help resolve issues regarding hammer performance, driving stresses in the pile and pile capacity. Provisions for the use of the PDA should be included in the contract documents. PDA testing and interpretation should be performed by a qualified professional engineer registered in the State of Delaware.

5. **Obstructions to Pile Driving.** Obstructions to drilling were encountered during several test borings at depths shallower than the recommended pile embedment depth. Due to the former use of the entire site as a shipyard and the northern portion of the site as a recently demolished warehouse, shallow obstructions (e.g., timber and concrete) will likely be encountered. Therefore, there exists a potential that the proposed piles will encounter obstructions during construction. The contract documents should include provisions for
pre-excavation or pre-augering if obstructions are encountered. The presence of obstructions may also require "offsetting" of pile locations during driving. Therefore, the project's structural engineer should be contacted to determine allowable tolerances for horizontal location. Driving tips should be utilized on all piles, unless pre-augering is performed.

6. **Pile Installation Review.** Installation of piles should be reviewed on a full-time basis by a qualified soil technician under the supervision of a geotechnical engineer licensed in the State of Delaware. The purpose of this review is to verify that piles have been installed in conformance with the driving criteria developed for the project. Records of the pile driving resistance should be maintained by a representative of the Owner to verify installation procedures and to provide technical assistance in the event that variations in driving are encountered.

7. **Vibration Monitoring.** Vibration monitoring should be performed at the site during the installation of piles. The purpose of the monitoring is to measure and document vibration levels being transmitted to nearby structures during the process of pile driving. Seismographs should be utilized to measure the peak particle velocities on the adjacent structures during driving. Provisions for adjusting construction methods, should excessive vibration occur, should be considered by the project team and should be addressed in the project documents. It is also recommended that a pre-construction photographic and video survey be performed of the adjacent structures to document the structural conditions prior to the start of the pile driving, and that a post-construction review be performed.

8. **Groundwater Control.** Apparently "perched" groundwater was encountered in several of the test borings during this evaluation at depths as shallow as 3 feet. Consequently, it is considered possible that localized perched groundwater may be encountered within the pile cap excavations. If groundwater is encountered, localized sumping will be required to the site storm sewer. Requirements concerning environmental quality of the sumped water should be coordinated with the project environmental consultant. Regional groundwater conditions will be encountered at depths similar to surface water levels in the nearby Christina River. It is recommended that wherever significant quantities of groundwater are encountered during pile cap excavations, the resulting excavation be over excavated by at least 4 inches and backfilled with AASHTO SP-57 stone to facilitate sumping and protect the exposed subgrade during construction.

9. **Excavation Safety.** All excavation and embankment construction should be performed in accordance with OSHA guidelines. Typically, previously placed fill soils and soft to medium consistency silty soils, as encountered near the surface and described herein as Strata B and C can be characterized by OSHA CFR Part 1926 Excavation Standards as Type C soils. Should it be required,
all temporary sheeting and shoring should be designed by a qualified engineer registered in the State of Delaware.

10. Available Data. All contractors interested in bidding on phases of this work which involve subsurface conditions should be given full access to this report so that they can develop their own interpretations of the available data.

These recommendations have been prepared according to generally accepted soil and foundation engineering standards and are based on the conditions encountered in test borings referenced herein. It should be noted that, although soil quality has been inferred from the interpolation of the test boring data, subsurface conditions between the sampled locations are, in fact, unknown. As a result, these recommendations may require modifications based on the conditions encountered and exposed during excavation and construction. Should any conditions encountered differ from those described in this report, Duffield Associates should be notified immediately in order to review and possibly modify these recommendations. The cost for this additional construction review is not part of this existing agreement. This report applies solely to the size, type, and location of the building renovation described herein. In the event that changes are proposed, this report will not be considered valid unless the changes have been reviewed and the recommendations of this report modified and reapproved in writing by Duffield Associates, Inc.