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September 20, 1999

Mr. Thomas Woosley, P.E.
Georgia Department of Natural Resources
Environmental Protection Division
Safe Dams Program
4244 International Drive, Suite 110
Atlanta, Georgia 30354

Subject: **Embankment Dam Slope Stability Analysis Review, Lake Petit Dam, Pickens County, Georgia (Our Reference No. 992039)**

Dear Mr. Woosley:

Schnabel Engineering Associates, Inc. is pleased to provide this report summarizing our review comments on consultant reports regarding stability evaluations of the subject embankment dam. This report has been prepared in accordance with our Agreement dated December 14, 1998.

1.0 Scope of Services

The purpose of our review is to provide the Georgia Department of Natural Resources, Environmental Protection Division (GaEPD) Safe Dams Program an opinion on the adequacy of the embankment dam stability evaluations performed on behalf of the Big Canoe Property Owners Association. The scope of services for our evaluation included the following:

1. Review of available information on the design and geotechnical properties of the dam materials.

2. Review available consultant reports on embankment dam stability.

3. Re-analysis of selected slope stability cross sections using embankment material properties and loading conditions assumed by the consultant.

4. Critically evaluate conclusions of consultant reports, including selected shear strength parameters, use of seismic design criteria, and methods to complete slope stability analysis.

5. Preparation of this report summarizing our findings and conclusions.

Our review did not include re-analysis of seepage conditions within the dam, dynamic modeling of embankment response to earthquake ground shaking, deformation analyses, laboratory or insitu field soil property testing, cost or quantity estimates, review of design and contract documents, or professional services not specifically noted above.

2.0 Background

The Lake Petit Dam is a zoned earth embankment dam constructed in 1972 with a total reservoir storage capacity of about 3,000 acre-feet. The dam is located on the Petit Creek drainage in the Big Canoe community in Pickens County, Georgia. Table 1 below provides a summary of dam engineering characteristics:

Table 1
Summary of Engineering Characteristics
Lake Petit Dam, Pickens County, Georgia

Dam category:	I
Dam age:	28 years
Dam type:	Zoned Earth Embankment
Shell material:	SM
Core material:	ML
Dam height (as measured from downstream toe):	115 feet
Downstream slope inclination (bench to bench):	2.5H to 1V
Overall downstream slope inclination (crest to toe):	3H to 1V
Crest length:	880 feet
Crest width:	35 feet
Crest elevation:	El 1,648 feet
Normal pool elevation:	El 1,635 feet

Routine inspections of the dam performed by the GaEPD representatives in April 1996 revealed seepage-related concerns on the downstream face of the dam. GaEPD recommended to the Big Canoe Property Owner's Association (POA) that an engineer perform an independent evaluation of the observed deficiencies and results of this evaluation be reported to GaEPD. The engineering services of Jordon Jones and Goulding, Inc. (JJ&G) and Piedmont Geotechnical Consultants, Inc. (Piedmont) were retained to perform a geotechnical investigation and stability analysis of the dam. The results of this study were not made available for our review. However, we understand that minimum calculated factors of safety for static and seismic loading

conditions under steady state seepage were below the minimum acceptable safety factors of 1.5 and 1.1, respectively, in accordance with the GaEPD Rules of Dam Safety. As a result, the consultants recommended construction of a blanket drain and earthen toe buttress over portions of the downstream slope of the dam to increase slope stability factors of safety to levels above the required minimum values.

The Big Canoe POA subsequently retained the engineering services of GeoSyntec Consultants (GeoSyntec) of Atlanta, Georgia to perform an independent review of the dam rehabilitation measures recommended by JJ&G and Piedmont. We understand that a more detailed investigation and analysis of dam seepage conditions, embankment material strength properties and embankment stability were undertaken by GeoSyntec to potentially justify less intrusive dam rehabilitation measures. The scope of our review is limited to the dam stability analyses provided in the following GeoSyntec reports:

1. GeoSyntec Consultants, "Evaluation of Stability and Rehabilitation Measures, Lake Petit Dam, Big Canoe, Georgia", Project Number GL0625-15, December 8, 1998.

2. GeoSyntec Consultants, "White Paper, Seismic Stability Analysis, Lake Petit Dam, Big Canoe, Georgia", Project Number GL0625-100, March 22, 1999.

3.0 Specific Review Comments

In general, it is our opinion that the reports referenced above adequately characterize embankment conditions under normal pool and estimated maximum water level (EML) conditions, as well as under the earthquake loading prescribed by Section 391-3-8-.09 of the Rules For Dam Safety as amended on October 26, 1998. We generally concur with the conclusions reached in the report regarding overall stability of the embankment under static and seismic loading, as well as measures recommended to mitigate potential surficial instability near the embankment toe under EML conditions. Specific review comments are provided below:

1. No stability analysis of rapid drawdown of the upstream face was performed in the reports reviewed and no comments on these analyses are provided. We have assumed that this stability concern has been satisfactorily addressed in other studies submitted to the GaEPD.

2. The level of earthquake shaking to be accommodated in the stability analysis of the dam, as characterized by the estimated peak horizontal bedrock acceleration value of 0.183g, is consistent with the recently amended GaEPD Rules For Dam Safety based on a 2 percent probability of exceedance in 50 years (i.e., an approximate 2,500 year return period of similar ground motions). We agree that this earthquake acceleration value is appropriate for use in stability analyses based on the dam location and foundation conditions.

3. From our review of the GeoSyntec data, and the results of our own re-analysis of stability cross sections through the dam, the estimation of pore water pressure distribution through the dam, in our opinion, provides the greatest effect on the resulting slope stability safety factors for this project. A thorough analysis and modeling of seepage pressures and distribution within the dam was performed by Geosyntec, with results for both the normal pool and estimated EML calibrated against existing piezometers installed on the downstream face. We noted that the pool elevation of the dam assumed in the seepage models analyzed by GeoSyntec is essentially the same for both the normal pool and estimated EML condition; however, the gradient of flow through the core and the downstream shell is steeper for the normal pool than for the EML condition. The seepage models incorporate existing foundation drains and estimated hydraulic conductivity of embankment shell, core and foundation materials. We understand no laboratory or insitu testing of hydraulic conductivity properties was performed as a part of the GeoSyntec study; however, a parametric study of estimated hydraulic conductivity properties was performed to examine the sensitivity of the seepage model to changes in assumed embankment permeability values as compared to actual piezometer pore water pressure measurements. It is our opinion that the sensitivity analysis study approach is appropriate, and the resulting hydraulic conductivity values assumed in the model are reasonable. Insitu testing of hydraulic conductivity properties of the dam embankment materials may be considered to verify the model assumptions. However, it is our opinion that the expense of performing such testing is not warranted based on the available piezometer data to calibrate assumed hydraulic conductivity values in the seepage model.

4. Our observations indicate that pore water pressures calculated within the dam by the SEEP/W model used by GeoSyntec are lower than those estimated by simply using hydrostatic pressures below the modeled phreatic surface. We found the resulting safety factors using purely hydrostatic conditions to be as much as 40 percent lower than safety factors calculated by GeoSyntec based on the modeled and calibrated pore water pressure distribution. It is our opinion that the less conservative distribution of pore water pressures within the dam estimated by the results of the GeoSyntec seepage model are appropriate based on the site data available to calibrate and verify the model. Our only recommendation on this point is that assumed boundary conditions (e.g., drain locations and efficiency, assumed EML pool level, etc.) be verified.

5. The effective stress (drained) shear strength parameters used in the stability analysis are considered appropriate based on our experience with similar embankment materials, and are substantiated by laboratory triaxial tests of multiple samples of these materials from the dam. It is our opinion that the use of undrained soil shear strength in analyzing the stability of saturated embankments under a short duration seismic event is appropriate. Agency guidelines regarding the stability of embankments under seismic loading, including the FERC and USACOE, refer directly or indirectly to the use of undrained shear strength parameters for evaluation of earthquake loading in a pseudo-static slope stability analysis. However, the literature suggests (Marcuson et al., 1992) that where the condition of drainage during an earthquake event is uncertain, the most conservative

result of the use of drained or undrained shear strength parameters should be selected. GeoSyntec, however, offers a convincing argument as to why the embankment soils for the subject dam cannot dissipate pore water pressures during the short duration of earthquakes expected in this region. We concur that undrained shear strengths are appropriate for the condition of earthquake loading.

6. For the earthquake loading condition, GeoSyntec uses an undrained soil shear strength envelope developed from CU triaxial testing. A vertical axis intercept of 1,000 psf and slope of 30 degrees characterize the resulting lower bound strength envelope used for the analyses. Review of the XSTABL analysis output provided in the referenced GeoSyntec report (1) appendix indicates the undrained strength envelope was used to estimate an equivalent S_u value as a function of effective vertical stress at each point along potential failure surfaces analyzed. It is our experience that the undrained strength envelope for embankment materials derived from Piedmont residual soils as assumed in the slope stability analysis by Geosyntec is not adequately conservative. By inspection of the estimated effective stress level along the most critical slip surface for the earthquake loading case under EML conditions the XSTABL output, the estimated S_u value along the potential slip surface would vary from just over 1,000 psf to about 5,400 psf. We would recommend adjusting the assumed strength envelope to intercept the vertical axis at the origin. This reduction in assumed strength is expected to decrease the safety factor under earthquake and EML loading conditions, but probably not below the minimum required value of 1.1. Should the resulting safety factor using the lower undrained strength values be less than 1.1, insitu testing to determine the variation of undrained strength (S_u) with depth in the embankment may be warranted. This type of testing may be accomplished using a truck-mounted dilatometer testing apparatus (DMT) and transducer probe that can provide a continuous record of estimated soil strength properties with depth. These probes may be correlated with existing borings where logs of earth materials are available and where embankment soils were retrieved for laboratory triaxial strength testing. Should the DMT results be in close agreement with the laboratory data, then the higher assumed undrained strength used in the GeoSyntec analysis may be justified.

7. We concur that liquefaction of embankment materials is not likely for this dam based on the several factors discussed in the GeoSyntec report.

8. It is our opinion that the earthquake loading analysis should be run under normal pool level conditions. Our experience suggests that this is a more traditional approach since the combined probabilities of having a maximum seepage pressure condition coinciding with the maximum design earthquake event are very small. For the condition analyzed by GeoSyntec, we would expect that this would only result in a higher safety factor under earthquake loading conditions than for the EML condition.

In summary, we generally concur with the results of the GeoSyntec reports for the Lake Petit Dam. Since the resulting safety factors are greatly affected by the way in which pore water pressures are modeled within the dam, verification of boundary conditions assumed in seepage

models are recommended. It is our opinion the assumed hydraulic conductivities for embankment materials assumed in the model are reasonable based on the results of the parametric study performed using the seepage model. We do not believe the assumed undrained shear strength envelope under earthquake loading conditions as reported from laboratory testing is adequately conservative. We recommend adjusting the undrained strength envelope to intercept the vertical axis at the origin while maintaining the slope of the envelope at 30 degrees. It is our opinion that the proposed limited dam rehabilitation measures as proposed by GeoSyntec to increase the surficial stability of the lower downstream face of the dam are appropriate, based on our limited knowledge of the existing dam conditions.

4.0 Limitations

We have endeavored to perform this report review in accordance with generally accepted geotechnical engineering standards. Our review has been limited to selected reports provided to us related to this project, as well as reference materials provided as an attachment hereto. We make no warranties, either express or implied, as to the future performance of the Lake Petit Dam based on our review comments provided in this report.

We trust the review comments provided herein will help form a rational basis for mitigation of dam deficiencies as observed by GaEPD. We look forward to assisting you on similar matters in the future. Please contact the undersigned should you have any question regarding this report.

Sincerely,

SCHNABEL ENGINEERING ASSOCIATES, INC.

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Attachments:
(1) References
(2) Paper by Marcuson et al., 1992

References

The following references were reviewed in preparation of this report:

1. Duncan, J.M., "State of the Art: Limit Equilibrium and Finite-Element Analysis of Slopes", in Journal of Geotechnical Engineering, Vol. 122, No. 7, pp. 577-596, July 1996.

2. Federal Energy Regulatory Commission (FERC), "Engineering Guidelines For the Evaluation of Hydroelectric Projects, Chapter IV – Embankment Dams", FERC 0119-2, April 1991.

3. Frankel et al., "National Seismic-Hazard Maps: Documentation", U.S. Geological Survey, Open-File Report 96-532, June 1996.

4. Georgia Department of Natural Resources, Environmental Protection Division, "Section 391-3-8-.09, Standards for the Design and Evaluation of Dams. Amended.", in Chapter 391-3-8, Rules For Dam Safety, October 26, 1998.

5. Marcuson, W.F., III, Hynes, M.E., and Franklin, A.G., "Seismic Stability and Permanent Deformation Analyses: the Last Twenty Five Years", in Stability and Performance of Slopes and Embankments – II, Proceedings of a Specialty Conference Sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers, Geotechnical Special Publication No. 31, Volume I, edited by Raymond B. Seed and Ross W. Boulanger, pp. 552-592, June 1992.

6. U.S. Army Corps of Engineers (USACOE), "Engineering and Design, Earthquake Design and Evaluation For Civil Works Projects", ER 1110-2-1806, July 31, 1995.