MICHIGAN SOIL CONSULTANTS

To: G.G. Brown, Engineering Manager

Date: October 25, 2006

Re: William Piper Associates: Glacier Way dam site soils evaluation

The Glacier Way dam site filter sample is not suitable for this project and all other data is summarized on the data calculation page, Appendix A, within the report. Included is a full assessment and recommendations to reduce seepage beyond 19.6 ft^3/day for design 2 if necessary.

The cover letter and full report is attached for your review, along with all calculations and data tables / charts. If you have any comments or concerns please contact me directly at (630) 768-1590.

Attachments: (Cover Letter)
(Report)

MICHIGAN SOIL CONSULTANTS

October 25, 2006

Peter Piper, Assistant Manager
William Piper Associates
6272 Stadium Boulevard
Ann Arbor, MI 48108

Re: Glacier Way dam site soils evaluation

Dear Mr. Piper:

1.0 SUMMARY

Several tests were administered per ASTM standards on supplied samples of soil obtained from the Glacier Way dam site. These tests ultimately determined if either of two proposed dam designs were acceptable. Gradation analysis was completed from data found by sieve and hydrometer tests conducted per ASTM standards D 421-85 and D-422-63 using an ASTM 152H hydrometer. This allowed us to classify the soil per the ASTM/USCS classification system D 2487-93. We also found the coefficient of permeability using permeameter tests and compared them against the empirically derived Hazen equation. Based on the gradation and permeabilities we determined the suitability of the coarse sand as a filter for dam design 1, and also estimated seepage loss under the dam for both designs. Each dam has a slightly different configuration but will ultimately be supported by these soils, therefore the stability and resistance to washout is crucial to the success of this project. The results of these tests determine what actions must occur before construction proceeds.

The soils have been found to be clayey sand and poorly graded sand for the fine and coarse samples, respectively. The gradation of the samples meets the Army Corps of Engineers criteria for soil restraint but fails to meet allowable filter permeabilities. Therefore, either a different filter media may be evaluated or design 2 may be chosen. For both soils, the Hazen approximation for permeability is not nearly within reason to allow this shorthand estimation to be used in the field. Unacceptable design 1 has an estimated seepage rate of 32.7 ft^3/day compared to an improved 19.6 ft^3/day for design 2. If this is deemed excessive several recommendations have been included that will get your project underway with minimal effort. All other data may be found on the data and calculation summary page, Appendix A.

2.0 INTRODUCTION

William Piper Associates is planning to build a dam at the Glacier Way dam site. Two designs are being evaluated based on their subbase soil characteristics to ensure they do not fail under the expected conditions. Before construction of the dams, soil criteria for using a filter must be met and the seepage loss under the dam must satisfactorily meet or exceed requirements. On October 24, 2006, Michigan Soil Consultants was contacted and asked to carry out these tests.

Seepage losses can determine the performance of the dam over its expected lifetime. Without proper filter characteristics and seepage flow, the dam may fail in a variety of ways including possibly washing away or not functioning to its intended degree. This may result in an unattractive, inefficient, unsafe, and possibly unusable dam. The purpose of this report is to detail our procedures and test findings while drawing conclusions and making some recommendations to ensure the success of this project.

The remainder of this document consists of test procedures, data results, conclusions, and recommendations. All preliminary data sheets and subsequent calculations have been included at the end of the document in Appendices A through I. Appendix B shows the soil gradation curves for the soils and Appendix J shows the proposed dams and corresponding flownets.

3.0 METHODOLOGY

To determine if these soils have satisfactory characteristics two important quantities were found. First, gradation analysis was completed according to ASTM standards D 421-85 and D 422-63. This included a hydrometer test for the fine soil using an ASTM 152H soil hydrometer. Additionally, constant and falling head tests were performed to determine the coefficients of permeability of both soils. It is important that the permeameter tests conducted in the lab use the soil sample compacted to the degree so that the relative density matches that of the in-situ relative density of 70%. Since this could affect the results much care was taken to ensure this was accomplished. The constant head test was performed in general accordance with ASTM D 2434-68, and the falling head used general laboratory procedures. These guidelines were generally followed and deviations that occurred are noted.

4.0 SOIL CLASSIFICATION

The soil classifications were found to be SC clayey sand and SP poorly graded sand for the fine and coarse sands respectively. These were found based on the soil gradation curves included in Appendix B as well as the uniformity coefficient C_u (equation 1) and coefficient of gradation C_z (equation 2).

$$C_u = D_{60} / D_{10} \tag{1}$$

C_u = Uniformity coefficient
D_{60} = Particle diameter for a 60% passing rate
D_{10} = Particle diameter for a 10% passing rate

$$C_z = [D_{30}^2] / [D_{10} * D_{60}] \tag{2}$$

C_z = Coefficient of Gradation

D_{60} = Particle diameter for a 60% passing rate
D_{30} = Particle diameter for a 30% passing rate
D_{10} = Particle diameter for a 10% passing rate

5.0 DATA RESULTS AND ANALYSIS

Overall, the coarse soil is not acceptable to serve as a filter medium for the fine grain soil. Therefore, only design 2 is acceptable which has a seepage rate of 19.7 ft^3/day. If this is acceptable then no further design modifications are necessary. A summary of numerical data, formulas, and calculations can be found in Appendix A, with additional data record sheets following. Summaries of these results are outlined below.

5.1 Filter Suitability

Soil restraint criteria were met however permeability criteria was not met. As a result either different filter media should be considered or dam design 2 should be evaluated further. The US Army Corps of Engineers has filter suitability criteria for dam designs utilizing a coarse grain filter with finer grain soil. This criteria is divided into two categories, soil restraint and permeability

5.1.1 Soil Restraint

Both soil restraint criteria were met, shown below in equations 3 and 4. Since these are satisfied the filter material is satisfactory for a dam application.

$$D_{15} \leq 5 * d_{85} \qquad (3)$$

D_{15} = Coarse grained particle diameter for a 15% passing rate
d_{85} = Fine grained particle diameter for a 85% passing rate

$$D_{50} \leq 25 * d_{50} \qquad (4)$$

D_{50} = Coarse grained particle diameter for a 50% passing rate
d_{50} = Fine grained particle diameter for a 50% passing rate

5.1.2 Permeability

Unlike soil restraint criteria, permeability criteria was not met. Equation 5 must be satisfied for the soils to be deemed acceptable. This expression has been evaluated and is shown in Appendix A. This confirms that we may not choose to build dam design 1 with this filter media.

$$D_{15} \geq 5 * d_{15} \qquad (5)$$

D_{15} = Coarse grained particle diameter for a 15% passing rate
d_{15} = Fine grained particle diameter for a 15% passing rate

5.2 Permeability

Fine soil permeability resulted in a value of 0.000002 cm/sec and for the coarse soil it was 0.016 cm/s. This result is intuitive as a coarse grained soil like gravel should transmit more fluid than one of little voids due to small particle size diameter.

The Hazen Equation, equation 6, is an empirical derivation of permeability and does not predict our measured values within reasonable tolerances. This formula results in permeability in mm/s, which can be converted to cm/s to be compared with the measured data.

$$k_{\text{(mm/sec)}} = 10 * D_{10\,\text{(mm)}}{}^{2} \qquad (6)$$

k = Hydraulic conductivity, (mm/sec)
D_{10} = Particle diameter for a 10% passing rate

This derivation resulted with a permeability of 0.029 cm/sec for the fine soil and 7.02 cm/sec for the coarse soil. Obviously these are extremely high when compared to actual values. Therefore, this shorthand equation should not be used for any field soil checks. This may have resulted from the rather poorly graded nature of the soils.

Furthermore, our fine soil D_{10} value of 0.017 mm falls below the recommended range of the equation applicability, (0.1 to 3.0 mm). Other soil types such as the clay in the fine soil may have influenced the results.

5.3 Seepage

We have found the seepage to be 32.7 ft^3/day for dam design 1 and 19.6 ft^3/day for dam design 2. These were found using flownets that have been provided by the design engineer. After converting units for the permeabilities measured previously, we can use equation 7, which is a variation of Darcy's Law to compute the seepage.

$$Q_{(\text{ft}^3/\text{day})} = k_{(\text{ft/day})} * \Delta H_{(\text{ft})} * (N_F / N_D) * W_{(\text{ft})} \qquad (7)$$

Q = Flowrate, (ft^3/day)
k = Hydraulic conductivity, (ft/day)
ΔH = Head drop from upstream to downstream dam, (ft)
N_F = Number of flowtubes
N_D = Number of equipotential drops
W = Dam width, (ft)

These solutions are tabulated in Appendix A.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The results from the data analysis demonstrates that the soil proposed to be used at William Piper Associates Glacier Way dam site is SP clayey sand and SP poorly graded sand for the fine and coarse sands respectively. These soils do not meet criteria satisfactorily for a successful dam using design 1. Here, the materials do not satisfy the criteria for the US Army Corp of Engineers permeability requirements, despite the acceptability of soil restraint. However, design 2 does not use a filter, which eliminates this inadequacy. Additionally, this design allows less seepage than dam design 1 at only 19.7 ft^3/day compared to 32.7 ft^3/day, which will provide a better end product that does not promote any piping and erosion that will yield a functional dam for a long time to come. Lastly, during field operations the empirically developed Hazen's Equation should not be use for field checks due to its giant discrepancy from actual measured values. All data has been summarized in Appendix A.

If dam design 2's seepage rate of 19.7 ft^3/day is considered excessive several simple remedies can be offered. We recommend adding another seepage blanket upstream of the dam, which would be the most cost effective way to lengthen the dam. This will alter the flow beneath the dam by extending its flow path, which reduces seepage. Other modifications could be made to the materials, such as grout injection into the soil to reduce permeability further, allowing less seepage beneath the dam.

If you need any additional information on the study we performed please don't hesitate to contact me directly at xxx.

Sincerely,

APPENDICES

Appendix A: Laboratory Data and Calculations

Appendix B: Soil Gradation Curves

Appendix C: Fine Sand Sieve Test Data

Appendix D: Coarse Sand Sieve Test Data

Appendix E: Fine Sand Hydrometer Test Data

Appendix F: Falling Head Permeability Test 1

Appendix G: Falling Head Permeability Test 2

Appendix H: Constant Head Permeability Test 1

Appendix I: Constant Head Permeability Test 2

Appendix J: Dam Design Flownets