GG Brown and Associates
800 Hayward Street
Ann Arbor, MI 48109

To: GG Brown, Engineering Manager

Re: Gradation Analyses and Permeability Tests for Glacier Way dam project (subcontract for Piper Associates)

Date: March 6, 2007

The gradation analyses and permeability tests have been performed on the coarse and fine soil samples given to us from Piper Associates for the Glacier Way dam project. Attached is a letter of transmittal and the report for your review prior to mailing.

Please feel free to contact me, with any questions that may arise, at extension 4-321.

All hours for this project have been billed to PO 05-14A.

Attachment

Michigan Soil Consultants
800 Hayward Street
Ann Arbor, MI 48109

March 6, 2007

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

Re: Gradation Analyses and Permeability Tests for Glacier Way Project

Dear Mr. Piper:

As requested in your letter dated February 5, 2007, the classification of the two soils as well as the suitability of the coarse soil as a filter has been determined. Also, the coefficients of permeability have been determined which have allowed us to estimate the seepage loss beneath the two proposed dams.

The coarse soil was determined to be poorly graded sand, SP. The fine soil was found to be clayey sand, SC. With the grain size distribution curves formed by these two soils, we were then able to determine that the coarse sand does pass criteria for being a filter for the fine soil set forth by the US Army Corp of Engineers.

The coefficients of permeability of the coarse and fine soils were found to be 8.7×10^{-3} cm/sec and 6.57×10^{-7} cm/sec, respectively. We determined the seepage loss beneath the dam Design 1 and Design 2 as 10.35 cubic ft per day and 6.21 cubit feet per day, respectively. This loss is excessive by our standards and we would recommend the addition of a seepage blanket on the upstream side of the dam to help reduce the amount of seepage loss on the downside of the dam, thus increasing the stability of your dams.

I hope that this information and the information that follows will be of use to you. We've greatly appreciated working with you and please feel free to contact me by phone at xxx or by email at xxx if any questions shall arise.

Sincerely,

Attachment

Engineering Manager

Gradation Analyses and Permeability Tests

Prepared for

William Piper Associates
6272 Stadium Blvd.
Ann Arbor, MI 48108

Prepared by

March 6, 2007

1.0 FORWARD

From your letter dated February 5, 2007, we understand that you intend to construct a dam at your Glacier Way site. There are two designs being proposed, both 100 ft in length. The main objectives of this report are to classify the coarse and fine soils given to us, determine the suitability of the coarse soil as a filter for the fine soil, determine the permeabilities of the two soils, determine the accuracy of Hazen's Equation on the approximation of the coefficient of permeability, and to determine the seepage loss beneath each of the two dam designs that are being proposed. We have completed the required tests to determine the above objectives. The purpose of this document is to present to you our findings, conclusions, and recommendations.

2.0 SUMMARY

The classification of the coarse soil was found to be poorly graded sand, SP. The fine soil was found to be clayey sand, SC. The coarse sand passed each of the three criteria which proved its suitability as a filter for the fine sand.

The coefficients of permeability for the coarse soil and the fine soil were found to be 8.7×10^{-3} cm/sec and 6.57×10^{-7} cm/sec respectively. It was found that this approximation was inaccurate due to key assumptions made in the formulation of this equation. With this we would recommend to not use this approximation during the calculation of further coefficients of permeability.

The seepage losses beneath dam Design 1 and dam Design 2 were estimated at 10.35 cubic ft per day and 6.21 cubit feet per day, respectively. These values are excessive by our standards and further design changes need to be made. We would recommend the addition of a seepage blanket in front of each dam design which would effectively reduce the amount of seepage loss beneath the dam and in turn ensure the stability of your proposed dam.

3.0 PROCEDURES

ASTM D 422: Standard Test Method for Particle-Size Analysis of Soils.
ASTM D 2434-68: Standard Test Method for Permeability of Granular soils (Constant Head).
Note: No ASTM standard for the falling head test performed on the fine soil. An in house standard test was performed.

4.0 DATA RESULTS AND ANALYSIS

The necessary data for construction of the proposed dam at your Glacier Way Project follows. This data includes the soil classifications, filter suitability, coefficients of permeability, and the seepage losses beneath each of the two proposed dam designs.

4.1 Soil Classification of Coarse and Fine Sands

It has been determined that the coarse sand is poorly graded sand, SP, and it has been determined that the fine sand is clayey sand, SC. These sand types were determined using the ASTM soil classification system and further calculations can be found in the appendix.

4.2 Suitability of Coarse Sand as Filter

The coarse sand is a suitable filter for the fine sand. The suitability of the coarse sand as a filter is important because it shows us that the soil can properly drain without clogging of the pores in the coarse sand and without washing out through the coarse sand. So here the filter is the coarse sand diameter and the soil is the fine sand diameter values that were obtained from Table 1 above. We will be using the US Army Corps of Engineers' procedure to help determine the soils suitability as follows:

Soil Restraint: $D_{15,filter} \leq 5 \cdot d_{85,soil}$ and $D_{50,filter} \leq 25 \cdot d_{50,soil}$ (1) and (2)

$0.30mm \leq 5 \cdot 1.950mm \rightarrow 0.30mm \leq 9.75$ **OK**

and $0.35mm \leq 25 \cdot 0.30mm \rightarrow 0.35mm \leq 7.5$ **OK**

Permeability: $D_{15,filter} \geq 5 \cdot d_{15,soil}$ (3)

$0.30mm \geq 5 \cdot 0.005mm \rightarrow 0.30mm \geq 0.025mm$ **OK**

Where $D_{(\%),filter}$ = particle size of coarse soil at (X)%
$D_{(\%),soil}$ = particle size of fine soil at (X)%

4.3 Permeability of Coarse and Fine Soils

Through our testing, we were able to determine the coefficient of permeability of both the coarse soil and the fine soil provided. The following values are as follows:

$$k = \frac{QL}{Aht} \tag{4}$$

Where Q = Volume of discharge, ml
L = length of specimen, cm
A = area of specimen, cm^2
h = head difference, cm
t = time of collection, sec

$$k_{coarse} = 8.7x10^{-3}\,cm/\sec$$
$$k_{fine} = 6.57x10^{-7}\,cm/\sec$$

The calculations and data from these tests can be found on pages 7 and 9 in the Appendix.

4.4 Hazen's Approximation on the Permeability of Fine Soil

Hazen's Equation has been found to be inaccurate when compared to our test results of the fine soil. We can determine the permeability of the fine soil in two ways. One way is to use an approximation equation known as Hazen's Equation and the other is to find it experimentally in the lab. The following are the results of the two calculations.

Hazen's Equation:

$$k(mm/\sec) = 10 \cdot D_{10}{}^{2} \quad (5)$$

k = $4x10^{-6}$ cm/sec

Laboratory Coefficient of Permeability: $k = 6.57x10^{-7}\,cm/\sec$

As can be seen from the above approximations of the coefficient of permeability of the fine sand, Hazen's Equation is off by an order of magnitude when compared to our laboratory result. Hazen's Equation is only off by one order of magnitude which is not as far off as one would think due to the wide range of magnitudes that soils can have, yet it clearly is not as accurate as actual laboratory tests. Hazen's Equation was found through observations made during experiments for loose, uniform sands. Because of this, if we are not using loose, uniform sands, then this approximation loses its accuracy as can be seen from the results.

4.5 Seepage Loss Beneath the Dam

The seepage loss beneath both dam designs has been determined to be excessive. The seepage loss beneath dam Design 1 was found to be 10.35 cubic feet per day while the seepage loss beneath dam Design 2 was found to be 6.21 cubic feet per day.

The seepage loss under your dam may be the single most important parameter in determining the stability of your dam because if the loss is too great, the soil beneath the dam may wash away, destroying the dam with it.

The following shows the seepage loss under your proposed dam for both design 1 and design 2. The following equation was used in the determination of the seepage loss:

$$q(ft^3/day) = k \cdot \Delta H \cdot \frac{N_f}{N_d} \cdot L \quad (6)$$

Where k: Coefficient of Permeability
H: Head loss across the dam
Nf: Total number of flow channels from flow net
Nd: Number of equipotential drops from flow net
L: Length of dam

The addition of the seepage blanket would effectively increase the number of equipotential drops below the dam which would decrease the seepage loss. The blanket lengthens the distance in which the water must travel which decreases the amount of water that can flow beneath the dam in a given day. This in effect decreases the seepage loss. A length of at least ½ the length of the dam is recommended for safety purposes.

5.0 CONCLUSIONS AND RECOMMONDATIONS

From the conclusion of our testing we have been able to determine the classification of the two soils, the suitability of the coarse sand as a filter, the permeability of the fine soil, and the estimated seepage loss beneath the dam in each design. The coarse soil was found to be poorly graded sand, SP, while the fine soil was found to be clayey sand, SC. With this we were then able to determine that the coarse sand met all criteria required to be a filter for the fine sand. We were also able to determine the coefficient of permeability of the coarse and fine soils as $8.7\text{x}10^{-3}$ cm/sec and $6.57\text{x}10^{-7}$ cm/sec respectively and also compare them to Hazen's equation approximation. We were able to determine that Hazen's equation is not an appropriate approximation in this situation due to certain assumptions needed to use that equation. Also, we were able to determine that the estimated seepage loss beneath dam Design 1 and dam Design 2 were 10.35 cubic ft per day and 6.21 cubit feet per day, respectively, which is excessive by our standards. With this we recommend adding a seepage blanket in front of both designs which would allow the seepage loss to drop to an acceptable level.

	Coarse Sand	Fine Sand
D_{10}	0.29 mm	0.002 mm
D_{15}	0.30 mm	0.005 mm
D_{30}	0.32 mm	0.150 mm
D_{50}	0.35 mm	0.300 mm
D_{60}	0.40 mm	0.430 mm
D_{85}	0.65 mm	1.950 mm

Table 1: Grain size distribution values for coarse and fine sands.

Coarse Sand: Coefficient of Uniformity, $C_u = \frac{D_{60}}{D_{10}} = \frac{0.40mm}{0.29mm} = 1.38$

1.38 is not > 6.0

Coefficient of Gradation, $C_z = \frac{D_{30}{}^2}{D_{10} \cdot D_{60}} = \frac{(0.32mm)^2}{0.29mm \cdot 0.40mm} = 0.88$

0.88 is not between 1 and 3

Less than 15% gravel present

SP – Poorly Graded Sand

Fine Sand: PI of 15 and LL of 31% plots above the A-line

Less than 15% gravel present

SC – Clayey Sand

Seepage Loss						
Dam	ΔH (ft)	k (cm/s)	Nf	Nd	Length (ft)	**q (ft^3/day)**
Design 1	100	6.57E-07	5	9	100	**10.35**
Design 2	100	6.57E-07	5	15	100	**6.21**

Table 2: Seepage loss under dam.