Monitoring and Test Blasting Recommendations for Old Hickory Lock & Dam Due to Proposed Quarry Operations

As a follow up to the Technical Paper published by Nashville District on March 28, 2016 the following recommendations are made for the blast testing and monitoring of Old Hickory Dam and Old Hickory Recreation area (Old Hickory Beach):

Instrumentation Needed

1. Minimum of four permanent seismograph locations and two additional nested piezometers on Government property are needed. The piezometers will be connected to the existing automated data collection system. The seismographs will be equipped with cellular modem that is accessible by both the Government and ILD's vibration consultant.

2. The instruments will be installed in the following locations, but are subject to change upon further evaluation of project data.

   Seismographs
   a. Seis-1, Old Hickory Beach Area
   b. Seis-2, Crest of the embankment, Station 28+90
   c. Seis-3, Foundation Sands, Station 28+90 at elevation to be determined
   d. Seis-4 Downstream Fill Area, Station 17+00, Offset 1+45

   Piezometers
   e. VPZ-11, Station 30+50, nested transducers elevations to be determined.
   f. VPZ-12, Station 28+95, nested transducers elevations to be determined.

3. The above instruments and locations have been chosen in order to record and evaluate the vibration levels, airblast levels, and changes in pore pressure resulting from nearby blasting. Existing piezometers will also be monitored for changed in pore pressure. The threshold peak particle velocities are listed in Table 1, the threshold airblast level is listed in Table 2 and the threshold pore pressure level is listed in Table 3.

4. The field of four seismographs at a relative logarithmic distances is to aid in the development of a site attenuation curve during test blasting and for the updating of this curve during the life of the quarry blasting. The ILD's vibration consultant will develop this curve and the Government will independently develop a curve. This data will aid the blast designer in developing more efficient blasts to limit adverse impacts to the embankment and the general public.

a. The Old Hickory beach location will record vibration and air blast data for each blast to ensure the public is not exposed to levels beyond thresholds governed by state law.
b. The crest and subsurface seismographs will monitor vibration of the embankment and the sand layer.
c. The downstream fill area is to monitor a far field location downstream of the toe of the dam.

Thresholds

1. The maximum allowable thresholds for peak particle velocities are based on Tennessee State Law and US Bureau of Reclamation recommendations for vibrations within embankment dams (Charlie 1985, 2000; Charlie et al. 2001). The water level threshold was derived from a stability analysis on the embankment and will be reevaluated during the course of the test blasting.

TABLE 1
MAXIMUM PEAK PARTICLE VELOCITY BY LOCATION

Structure Type	PPV (in/sec)	Source
Old Hickory Beach Area	1.0	TN Code
Embankment Crest	1.0	USBR
Embankment Subsurface	1.0	USBR
Downstream Fill Area	1.0	TN Code

Note: Charge weights per delay to achieve these vibration limits should be established by ILD's seismic and vibration consultants. Vibration Limits for all non-government owned structures must conform to the Laws of the State of Tennessee.

TABLE 2
MAXIMUM AIR BLAST PRESSURE THRESHOLD

Structure Type	decibels (dB)	Source
Old Hickory Beach Area	133.0	EM 385-1-1

Note: The overpressure limit shall be lowered if it proves to be too high based on damage or complaints. This value is from the Engineering Manual 385-1-1.

2. The new piezometers will be nested fully grouted vibrating wire piezometers. Nested transducers will monitor the pore water pressures of the sand layer and other zones within and below the embankment. Thresholds here are for reactions due to quarry operations.

TABLE 3
PORE PRESSURE LEVEL THRESHOLD

Material	Water Level (Elevation)
Alluvium Sand	448.6 (maximum)
Foundation and other materials	+2 ft. above previous reading

Note: The threshold elevation for sand is below the pore pressure level that resulted in a factor safety of 1.5 against liquefaction.

Equipment Specifications

1. Seismograph Equipment

Equipment for particle velocity monitoring will be 3-channel (3 seismic channels) seismograph units capable of digitally storing collected data. The blast monitoring equipment will be automatically triggered for recording vibration. Equipment will be capable of recording time histories and summaries of peak motion intensities, frequencies and USBM RI8507 ppv-frequency plots. Records will include date, time of recording, operator name, instrument-number and date of last calibration. At a minimum, seismographs shall be recalibrated annually.

Instruments will have a flat frequency response between two and 250 Hz for particle velocity. The seismograph and supplemental software will be capable of calculating peak accelerations and peak displacements from the velocity waves. The seismograph will be able to sample at the rate of 15,000 samples per second or more in order to have reproducible results in frequency, acceleration, PPV and displacement at both high and low frequencies. The seismograph used will be capable of recording particle velocity for three mutually perpendicular components of vibration in the range generally found with blasting around sensitive structures. The units will be self-contained except for external geophones and microphones. The units will be programmed with specific data on each site of placement which includes seismograph location, calibration signal, date and time, and closest distance to the blast area.

2. Piezometer Equipment

   Vibrating wire sensors will be model 4500S 350 kPa as manufactured by Geokon Inc, of Lebanon, New Hampshire. One Geokon LAB3 transient voltage surge suppression module (board only) installed per vibrating wire sensor. All equipment needed to properly install, monitor, and maintain these sensors will be provided by the ILD's vibration consultant including drilling for the installation. Piezometer transducer sensors will be automated to facilitate data collection frequencies required. The Corps of Engineers will be onsite during drilling and installation with a qualified geologist or geotechnical engineer to verify and monitor all installation procedures. Installation diagrams will be created by Corps of Engineers geologist or geotechnical engineer with data supplied by ILD's consultant.

3. Communication Equipment and Programming

   Data logging equipment for the new equipment will be installed and connected to the existing system that is in an enclosure at the locations onsite. The system contains all components and accessories to read, process, and log the instrumentation to be installed. All cable entries will be sealed to prevent moisture intrusion. The enclosure contains a humidity sensor or equivalent.

   The datalogger is programmed to read all instrumentation on 15 minute intervals. The vibrating wire frequency and amplitude along with thermistor temperature will be recorded. Data table will be filed to the memory card daily as a backup.

   The seismographs will each have an attached cellular modem and the seismographs units will be programmed by ILD's vibration consultant. Both the Government and the Vibration consultant will have remote access to the units.

Test Blasting, Blasting Plans Notification and Records

1. Test Blast Requirements

   The above instrumentation shall be installed and operating prior to the start of blasting. All blasts will be monitored at these permanent locations.

   The ILD's vibration consultant shall develop a blasting vibration site curve from the measured vibration levels. This site curve shall be used by ILD's

blasting consultant to determine the maximum explosive charge weight per time delay given the distance between the structure and the blast.

Compliance criteria in the above tables shall be controlled by modifying the amount of the explosive charge weight per time delay, based upon site vibration propagation characteristics determined from blasting vibration measurements.

The test blast program shall be conducted and reported within procedures outlined in the sections of this memorandum covering vibration control, air blast control, and pore water pressure. The Government will communicate pore water pressure readings and conduct analysis and inform ILD of results and how the blasting is impacting Government property.

The Quarry Operator will share the test blasting plans showing the location(s) and extent of the blasted areas. The test blasting plans shall include the blasting patterns and the locations of patterns shall be drawn on plan sheet(s) (maps) in scale by providing coordinates of the individual blast shot area. Include information as to the number of holes, bottom and top elevations of holes, coordinates of each hole, amount of explosives and stemming per hole, type of delay in holes, sequence and pattern of delays, maximum peak particle velocity from each instrument, and peak overpressure reading in pounds per square inch and decibels from each airblast sensor. Information provided should also include a written analysis of each test blast, including the maximum particle velocity in each plane, associated frequency in each plane and peak true vector sum of particle motion.

In addition to the submission of an initial test blast plan, the Quarry operator will submit documentation of each blast prior to proceeding forward to the next blast test. The documentation shall include, but not be limited to, a written analysis of each blast, all observed test blasting data. The record of each blast performed shall be submitted no later than 24 hours after completion of each test blast until the test blast program is completed. It is expected that the initial test blast will be used to develop knowledge of ground conditions, propagation characteristics, etc. At the conclusion of the test blast program, the Quarry operator and Government will examine all reports, surveys, test data, and other pertinent information and discuss a path forward.

2. Blasting Plan Distribution

The quarry's blasting and vibration consultants will provide the individual blast plans to the Government prior to each test blast. After each blast the

updated shot plans along with the seismograph readings and analysis will be provided to the Government. These blasts plans shall contain the state required minimum items listed below.

a. Name of company or contractor;
b. Location, date and time of blast;
c. Name and signature of blaster on charge;
d. Type of material blasted;
e. Number of holes, burden and spacing;
f. Diameter and depth of holes;
g. Types of explosives used (trade name);
h. Total weight of explosives used;
i. Maximum weight of explosives and maximum number of holes per delay period;
j. Method of firing with overhead diagram of the delay pattern;
k. Direction and distance in feet to nearest dwelling house, public building, school, church, commercial or institutional building normally occupied, neither owned nor leased by the person conducting the blasting;
l. Weather conditions;
m. Type and height or length of stemming;
n. Type of delay blasting caps used and delay periods used (trade name);
o. Kind of mats or other forms of protection used;
p. The person taking the seismograph reading shall accurately indicate the location of each seismograph used, and its distance from the blast;
q. Name of person and/or firm analyzing the seismograph record;
r. Name of driller;
s. Any anomalous or unusual conditions encountered during drilling;
t. Location of holes not loaded or those requiring non-typical loading; and
u. Documentation of measures taken to compensate for anomalous or unusual conditions.

3. The Government will analyze the results of the blasts on the embankment and recreation area. This will include evaluating the air blast levels, peak particle velocity of the readings of each seismograph and pore water pressures in the piezometers.

4. The allowable charge weight per delay shall be based on vibration levels that do not cause damage to nearby structures or exceed the thresholds developed above. The data will be analyzed to determine if the thresholds should be changed.