



DEPARTMENT OF THE ARMY  
NASHVILLE DISTRICT, CORPS OF ENGINEERS  
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NASHVILLE, TENNESSEE 37203

IN REPLY REFER TO

Executive Office

December 7, 2015

Honorable Jim Cooper  
605 Church Street  
Nashville, TN 37219-2314

Dear Representative Cooper:

Merry Christmas! I hope this letter finds you enjoying a wonderful holiday season, especially because we get to enjoy it here in this beautiful city. Enclosed you will find our preliminary report entitled "Analysis of the Potential Vibration Impacts to Old Hickory Lock and Dam from Proposed Quarry Operations" in response to your November 12, 2015, letter related to the Industrial Land Developer's (ILD) proposed quarry located near the U.S. Army Corps of Engineers, Nashville District's Old Hickory Lock and Dam project.

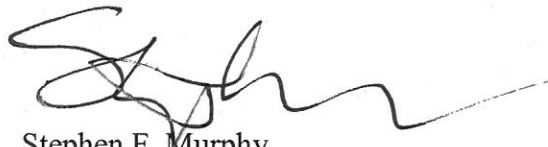
The Nashville District also has concerns about the long term operation of a quarry next to Old Hickory Lock and Dam. The enclosure contains an executive summary of our analysis but also goes into detail to outline these concerns, as well as to make several recommendations. The immediate challenge for the Corps, unfortunately, is that Congress has not legislated authority that would give the Corps of Engineers direct authority to evaluate and permit projects such as the quarry unless they impact waters of the U.S. The Corps' existing authority under Section 404 of the Clean Water Act only allows jurisdiction over any quarry construction that would result in the discharge of dredged or fill material into waters of the United States. At this time, ILD has indicated that it will avoid any such discharges and, as a result the Corps has no jurisdictional regulatory authority. The Corps is currently working with ILD to establish the boundaries of these waters upon their property and to verify that all waters of the United States will be avoided.

The concerns we have about the potential effects of blasting deal primarily with the impact of the blasting on the near earthen embankment of the Old Hickory Dam. However, the Corps of Engineers lacks the legal authorities to directly regulate the blasting operations of the quarry as currently proposed. One possible solution, given your current leadership, influence, and close involvement with this issue, would be the creation of an interagency task force that would include all appropriate state and federal agencies involved in quarry operations. The task force, possibly under your leadership, could ensure that all measures are taken to ensure the safety of the federal facilities at Old Hickory as well as to the surrounding area.

The Corps continues to work with the state and federal agencies who do have the authority to regulate this quarry operation to share our concerns and to provide our technical expertise on the potential vibration and other impacts of blasting on the Old Hickory Dam and other receptors. Coordination with these agencies and with the permit applicant should result in consideration of our concerns and implementation of ways to address these concerns through the

permitting processes of the state and other federal agencies involved. Our analysis recommends several measures that should reduce the risk to our structure from this proposed operation as well as reduce the impacts to our personnel and the recreating public. Primary among these measures is the Corps plan to request that seismic monitoring be conducted by a third party to determine and measure the impacts of blasting at or near our project for as long as the quarry is in operation and that the Corps be furnished a copy of the results.

It is my sincere hope that my staff and I can meet with you at your earliest convenience, possibly this week, to discuss our report with you in person, and to continue working toward solutions that will ensure the safest future for Old Hickory Lock and Dam and the recreating public.

A handwritten signature in black ink, appearing to read 'S. F. Murphy', with a long horizontal flourish extending to the right.

Stephen F. Murphy  
Lieutenant Colonel, U.S. Army  
District Commander

Enclosure



# Preliminary Analysis of Potential Vibration Impact to Old Hickory Lock & Dam from Proposed Quarry Operations

U.S. ARMY CORPS OF ENGINEERS

BUILDING STRONG®

**SUBJECT:** Response to Congressman Cooper's November 12, 2015, Request for Information to the Quarry Adjacent to Old Hickory Lock and Dam

**EXECUTIVE SUMMARY:** Old Hickory Lock and Dam is a combination of concrete gravity sections and earth embankment. Based on our assessment, the U.S. Army Corps of Engineers, Nashville District (USACE) has no immediate concerns about the concrete structures at Old Hickory Lock and Dam from anticipated quarry blasting. The dam has a low susceptibility to damage from the maximum probable earthquake estimated to have an acceleration of 0.14g at the dam. This earthquake would subject the concrete structures to much greater vibrations than expected from the quarry blasting. The calculated vibrations from the quarry at the anticipated distances and charge sizes are well below thresholds of concern for the concrete structures.

Regarding the earthen embankment portion of the dam, there are some soils under the left end of the dam that potentially could be a concern for liquefaction and loss of strength leading to an embankment slope failure under the right set of circumstances. Calculated vibration levels are right at or below threshold levels recommended based on case and field studies by others. Additionally, we've made some preliminary stability analyses that show pore water pressures induced by blast vibrations would have to be very high to cause this. Even then, the slope failures are not large enough to lead to a catastrophic breach of the dam and loss of the reservoir. Thus we consider our concerns to be conservative.

However given the visibility of this issue, the concerns expressed, and magnitude of the impacts if the dam were to be breached, we feel it necessary to take a conservative approach in addressing dam safety issues. We have provided some recommendations that will satisfy dam safety concerns and be protective long term of the dam. Because the regulatory authority regarding blasting lies with other agencies it is important these recommendations become an enforceable part of a permit. In order to ensure this, a facilitated meeting between USACE, regulatory agencies, and the quarry developer needs to occur to discuss our concerns and the incorporation of the recommendations to mitigate them. This will ensure all parties are working toward assuring the safety of the project.

It should be recognized that any measures taken to ensure dam safety and the safety of project staff and the recreating public on Corps property will not necessarily be protective of the surrounding residential and commercial community. Likewise, measures taken to protect the residential and commercial community may not necessarily be protective of the dam. All potential sensitive receptors must be taken into account and impacts evaluated.

This assessment is preliminary and is prepared pursuant to Congressman Cooper's request to our agency for information.

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## **RESPONSES TO CONGRESSMAN COOPER'S LETTER DATED NOVEMBER 12, 2015:**

**General:** When considering Probable Failure Modes due to explosive induced vibrations on an earth embankment, there are 2 main ways the embankment could be damaged. The first would be subjecting the dam to large enough vibrations that the additional seismic loading could reduce the factor of safety against a stability failure of the embankment slopes. Based on the 1983 Old Hickory Seismic Study, the calculated acceleration expected at the project from the maximum probable earthquake is 0.14g. Based on correlations from the United States Geological Survey this would be described as a level VI earthquake with perceived shaking to be strong but the potential for damage light. Estimated peak particle velocities would be between 3 and 6 in/sec. These are likely much higher than anything the quarry would generate.

A more credible failure mode of concern is the potential for blast induced pore pressure increases in the loose, saturated fine grained sands and silts in the foundation beneath the left end of the embankment. If the vibrations were strong enough, pore pressures could increase such that foundation soils lose their shear strength leading to slope instability in the embankment. How significant this would be as a failure mode would depend on the size, location and elevation of the instability and its relationship to the lake level. The question then is the threshold at which one becomes concerned about this and how that compares to vibration levels generated by quarry blasting. More on this is discussed below but suffice it to say actual instrumented field test blasting and monitoring for foundation response is needed to answer this question with the necessary degree of certainty.

**Question 1.** *Was your analysis based upon ILD's "Assessment and Modeling of Blast-Induced Vibration and Airblast for the Quarry Project on Burnett Road?"*

**Response:** Yes USACE's analysis included a review of ILD's assessment. In addition, the analysis which is on-going consists of a literature review for case study history, a USACE-wide query for similar experience, a review of blasting requirements that have been placed on recent projects, a review of the foundation data at Old Hickory Dam, and discussions with an outside blast consultant and a blast expert at USACE's Engineer Research and Development Center (ERDC) laboratory in Vicksburg, MS. The Nashville District is currently analyzing stability based on the foundation conditions with various assumptions regarding foundation response to blasting. The Nashville District also manages Barkley Lock and Dam, a project that is instrumented with seismic monitors due to its location within the New Madrid Quake zone. There is also an active railroad that runs across the top of Barkley dam resulting in repetitive vibrations that have been recorded by these instruments. The Corps is gathering this data and will review it to determine if there is any correlation to the analysis of the blast effects at Old Hickory Dam.

The assessment provided by Industrial Land Developers (ILD) was prepared by Austin Powder Company (APC). USACE reviewed the assessment for its applicability and compliance with standard practice and published guidance. The equation used to calculate ground blast vibrations in terms of peak particle velocity (ppv) is the industry accepted method scaled distance approach and is the same equation that was specified for the Kentucky Lock project blasting in order to protect the

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adjacent lock and dam from damage. The equation ppv is based on the size of charge, distance from the blast, and factors related to site conditions.

$$ppv = k(D/W^m)^{-\beta}$$

D is the distance to the point of concern

W is the charge weight per delay

k is a ground transmission or attenuation factor

m and  $\beta$  are empirical site constants.

For quarry blasting, characterized by row or line charges, m,  $\beta$ , and k are chosen as 0.5, 1.82, and 182, respectively, by APC, as cited in the ISEE Blasters Handbook. For sensitive structures located in close proximity to the blasting, it may be appropriate to adopt more restrictive values for k and  $\beta$ . APC used k = 242 and  $\beta$  = 1.6, again as recommended in the ISEE Blasters Handbook, to represent a general construction scenario with an upper bound on the confidence level. Calculations for ppv's were then determined for various distances from the blasting area while varying the charge weight per delay, k and  $\beta$ , as shown below in Tables 1 and 2 below.

TABLE 1

		Peak Particle Velocity, inches/sec							
k = 182 $\beta$ = 1.82		Distance, ft							
Charge Weight per delay, lbs		250	500	600	750	1000	2000	3000	3500
	100	0.52	0.15	0.11	0.07	0.04	0.01	0.006	0.004
	150	0.75	0.21	0.15	0.10	0.06	0.02	0.008	0.006
	200	0.98	0.28	0.20	0.13	0.08	0.02	0.011	0.008
	250	1.20	0.34	0.24	0.16	0.10	0.03	0.013	0.010
	300	1.41	0.40	0.29	0.19	0.11	0.03	0.015	0.012
	350	1.63	0.46	0.33	0.22	0.13	0.04	0.018	0.013
	400	1.84	0.52	0.37	0.25	0.15	0.04	0.020	0.015
	450	2.04	0.58	0.42	0.28	0.16	0.05	0.022	0.017
	500	2.25	0.64	0.46	0.30	0.18	0.05	0.024	0.018
	1000	4.22	1.20	0.86	0.57	0.34	0.10	0.046	0.035

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TABLE 2

k = 242 β = 1.6		Peak Particle Velocity, inches/sec							
		Distance, ft							
		250	500	600	750	1000	2000	3000	3500
Charge Weight per delay, lbs	100	1.40	0.46	0.35	0.24	0.15	0.05	0.026	0.021
	150	1.94	0.64	0.48	0.33	0.21	0.07	0.036	0.028
	200	2.44	0.81	0.60	0.42	0.27	0.09	0.046	0.036
	250	2.92	0.96	0.72	0.50	0.32	0.10	0.055	0.043
	300	3.38	1.11	0.83	0.58	0.37	0.12	0.063	0.050
	350	3.82	1.26	0.94	0.66	0.42	0.14	0.072	0.056
	400	4.25	1.40	1.05	0.73	0.46	0.15	0.080	0.062
	450	4.67	1.54	1.15	0.81	0.51	0.17	0.088	0.069
500	5.08	1.68	1.25	0.88	0.55	0.18	0.095	0.075	
1000	8.85	2.92	2.18	1.53	0.96	0.32	0.166	0.130	

The distance from the nearest quarry property boundary, which is a conservative assumption for the blast location, to the left-most end of the Old Hickory Dam embankment is about 600 feet; to the nearest lock wall is about 3000 feet; and to the powerhouse is about 3,500 feet. Assuming a charge weight per delay of 500 lbs., which is described by APC as a production charge - or a "...heavy AN/FO explosives product charge...", the resulting ppv's are highlighted in Tables 1 and 2 above and summarized in Table 3.

TABLE 3

Old Hickory Dam Feature	Distance from quarry boundary to feature	Peak Particle Velocity, in/sec*	
Left-most embankment	600 ft.	0.46	1.25
Nearest lock wall	3000 ft.	0.024	0.095
Powerhouse	3500 ft.	0.018	0.075

For the concrete structures like the lock wall and powerhouse, the generally recognized threshold above which concern for damage to structures due to vibrations becomes a consideration is 2 in/sec. For comparison purposes, during the blasting adjacent to Kentucky Lock and Dam the following maximum allowed ppv's were specified in order to protect the structures at Kentucky Lock:

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TABLE 4

KY Lock Feature	Peak Particle Velocity in/sec, during production
Nearest lock wall and U/S cofferdam	4
Lock Control Building	2
Transmission Towers	4
Switchyard	2

The calculated values in Table 3 for the concrete structures are between 1 and 2 orders of magnitude less than the thresholds, resulting in a preliminary conclusion that the concrete structures at Old Hickory Lock and Dam will not be impacted by quarry blasting.

As for the embankment and concern for foundation liquefaction, in a study done in the USSR (Puchkov 1962) it was found that liquefaction did not occur in any saturated soil subjected to ppv's less than 2.7 in/sec. For liquefaction concerns, the Bureau of Reclamation (Charlie 1985) recommended the following:

"Blasting is not recommended near operating dams constructed of or having foundations consisting of saturated loose sand and silts that are sensitive to vibrations. ...If blasting is required, peak particle velocity and pore-water pressure should be monitored and evaluated at several locations in the dam, foundation soils, and abutment. Peak particle velocities should be kept below 2.5 cm/sec.", (1 in/sec).

Subsequent studies of field behavior of full-scale earthfill and tailing dams subjected to blast vibrations indicates that ppv less than 1.0 in/sec, 2.0 in/sec, and 3.9 in/sec are reasonable thresholds to minimize pore pressure buildup in dams constructed of or on soils sensitive, moderately sensitive, and not sensitive to vibration, respectively (Charlie 1985, 2000; Charlie et al. 2001). Moreover, ppv less than 2.76 in/sec yield little to no residual pore pressures; less than a tenth of what would be required to initiate liquefaction and is in agreement with the USSR (Puchkov 1962) reports of the same (Charlie et al. 2013). Therefore, the proposed thresholds above of 1.0 in/sec, 2.0 in/sec, and 3.9 in/sec can be considered conservative provided that if any observed residual pore pressures occur they are allowed to dissipate prior to the next blast.

A layer about 15 feet in thickness of saturated loose sands does exist in the foundation under a portion of the Old Hickory embankment nearest the left abutment. Under the assumption that the quarry could conduct blasting immediately adjacent to the quarry property line nearest the dam, using the more restrictive values for  $k$  and  $\beta$ , and sensitive soils susceptible to pore pressure increase and loss of strength the calculated ppv of 1.25 in/sec at a distance of 600 feet (highlighted in Table 2 above) just exceeds the suggested threshold of 1.0 in/sec. However, this is still well below the observational significant residual pore pressure limit 2.76 in/sec and laboratory and/or field-testing

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may further reduce the empirical values ( $k$  and  $\beta$ ) used to estimate the ppv. It is worthwhile to note that increasing the distance from 600 feet to 750 feet drops the estimated ppv to 0.88 in/sec. Similarly, decreasing the charge weight per delay to 400 lbs. results in a reduction of the estimated ppv to levels equivalent to the suggested threshold. In summary, increasing the distance between the charges and the dam (the buffer) and limiting the charge size would both serve as practical measures to eliminate blasting impacts on the dam foundation.

These estimates are all based on assumed charge weights, blasting in close proximity to the left abutment, and attenuation factors that are not necessarily site specific. Therefore, if the quarry development is allowed, ILD should be required to undertake a test blast program monitored by the Corps. From this, site specific conditions can be determined so that blasts can be designed to ensure that vibrations stay below a protective threshold and to ensure that foundation response to these blasts can be monitored. The Corps has two vibrating wire piezometers, VWP 1 & 2, located in the sands under the left end of the embankment that will provide pore pressure response.

Also of concern is the effect of long-term repeated blasting on the dam, as might be expected to occur over the economic life of a quarry. This is again dependent on the foundation response and the transient response in the pore pressures as well as how fast those pressures dissipate. If the blasting were done with such regularity that any excess pore pressures generated in the foundation were not allowed to dissipate prior to the next blast, pore pressures could build up to such levels that the foundation soils could lose their strength, resulting in instability of the embankment. This is not likely given the time between typical production blasting in quarries but is another factor that must be confirmed with ILD.

#### Airblast Vibrations

Airblast vibration and noise levels are addressed by APC. While there are methods for calculating airblast vibrations and noise levels, there are a number of variables and the calculations have their limitations. The airblast vibrations and noise levels will likely be more problematic during initial quarry development when blasts are shallow as opposed to during production blasting when it occurs below ground level down in the quarry pit. Tennessee state requirements limit noise levels to a maximum of 140 dB. The report calculations "suggest" airblast levels from production blasting will be in the 110—115 dB range with occasional readings up to 120 dB. However, these calculations were performed at a single distance of 2,000 ft. Just as with the ground vibrations, airblast vibrations will have to be determined in a test blast program with blasts designed to be protective of nearby structures and people with continuous real-time monitoring during regular quarry blasting operations.

#### Flyrock

The Corps has identified an additional area of concern that must be addressed by APC. The potential for flyrock and proposed methods to prevent it are not addressed in APC's assessment but pose a likely hazard to the public at the nearby Corps recreation beach area as well as to boaters in close proximity. Flyrock will be most problematic during the early stages of development and mining because blasting will be nearer the surface. This problem will be somewhat mitigated once blasting is lower down in the excavated pit. Properly designed blasts and cover matting over blast areas should address this.



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**Question 2.** *Please list detailed conditions used for your vibration analysis (specific magnitude, frequency, duration, etc.).*

**Response:** As discussed above, the Corps made various calculations using the standard equation for computing peak particle velocity with different combinations of the various variables and those results are in Tables 1 and 2 above. However, the Corps must still confirm the blast parameters from APC and ILD to include the exact distances between the proposed quarrying operations and the sensitive structures, charge weights per delay, hole diameters, hole numbers and spacing, depths, production bench widths, frequency of blasts, etc. Site specific values will need to be determined from actual blast tests.

As acknowledged by APC, air blast predictions are "...quite complex." and subject to even more variables and uncertainty, not the least of which are atmospheric conditions during a blast. While these are likely to be worse during initial quarry development, the estimated values should be used for rough order of magnitude and will need to be verified during a test blast program and continuously monitored during blasting operations.

**Question 3.** *Did your analysis confirm ILD's findings for the "worst case scenario"?*

**Response:** USACE does not agree ILD's analysis represents the worst case as it pertains to potential impacts on the embankment portion of the dam. They looked at vibration impacts on the nearby residences and commercial business and concluded that if they are protective of these structures that they will be protective of the Corps' concrete structures which are further away. This is likely the case for the gravity dam and lock monoliths but we do not assess that this is accurate for the closer earthen embankment. ILD did not address vibration impacts on the soils beneath the left end of the embankment which will be closest to the quarry operations.

**Question 4.** *Did your analysis include vibration calculations to the earthen dam?*

**Response:** Yes. See previous responses.

**Question 5.** *Was your vibration analysis conducted using site-specific information for both Old Hickory Dam and the adjacent earthen dam?*

**Response:** No, see previous responses. Site-specific information that takes into account blast design and geologic conditions would be obtained from an instrumented test blasting program.

**Question 6.** *Please provide the latest piezometer readings for the earthen dam.*

**Response:** Data on the recently installed automated vibrating wire piezometers is enclosed. The Corps has two instruments with sensors set in the loose saturated sands that are a concern beneath the left end of the embankment. These two instruments would be used to monitor blast induced pore pressure increases.



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**Question 7.** *Please specify what other "impacts to aquatic resources" were reviewed.*

**Response:** The Corps Regulatory office is evaluating the extent of aquatic resources within the property that may be subject to regulation under Section 404 of the Clean Water Act. Regulatory conducted a site visit on December 1st and requested additional information from the developer to verify the delineation of aquatic resources. Upon receipt of the revised delineation and mine plan, Regulatory will determine if a Clean Water Act permit would be required for the discharge of dredged or fill material associated with quarry activities.

**Overall Nashville District Corps of Engineers Recommendations:**

The Corps recommends the following requirements and conditions be met to ensure the safety of project staff and the recreating public, and to ensure the safety and integrity of the Lock and Dam structures. This list is not all inclusive but addresses some of the major concerns. The developer's permit should be contingent on these being enforceable requirements with tangible consequences if violated.

- a. A site specific test blast program should be conducted by ILD to assess site specific conditions and dam response both from ground vibration and air blast. From this, blast design parameters will have to be established such that appropriate thresholds to ensure long term dam safety to structures, and safety to dam staff and the recreating public are met.
- b. The quarry developer should be required to furnish, install, and maintain the necessary permanent monitoring equipment on the dam for the life of the quarry. For ground vibrations, this will require permanent monitoring equipment be installed at key locations both on the surface and at depth to measure longitudinal, transverse, and vertical ground vibrations.
- c. All data should be provided by ILD in a timely manner to USACE for an independent evaluation.
- d. The quarry operator and USACE should jointly conduct and document a pre-blast survey of the Old Hickory Lock and Dam project.
- e. The quarry owner must address possible airblast impacts to USACE on the Old Hickory recreational beach and to boaters in close proximity.
- f. The quarry owner must address flyrock concerns on the Old Hickory recreational beach and to boaters in close proximity.
- g. For every shot during the life of the quarry, the Nashville District and Old Hickory project staff should be informed within a reasonable time prior to every shot so that project personnel are aware of a pending shot.