LVMWD Report No. 2433.02A

Evaluation of Blasting Excavation
Proposed 5 MG Tank at Las Virgenes Reservoir

for Las Virgenes Municipal Water District

May 2011
Revised July 2011

LVMWD Report No. 2433.02A

Evaluation of Blasting Excavation Proposed 5 MG Tank at Las Virgenes Reservoir

---

Las Virgenes Municipal Water District

Project Manager	David Lippman, PE

AECOM

Project Manager	Dan Ellison, PE
Geotechnical Engineer	Stan Kline, GE

REVEY Associates

Principal	Gordon F. Revey

Project No. 60196699

May 2011
Revised July 2011

5851 Thille Street Suite 201 Ventura, CA 93003

Table of Contents

AECOM
2101 Webster Street
Suite 1000
Oakland, CA 94612
www.aecom.com

510.419.6000 tel
510.419.5355 fax

July 15, 2011

Mr. David Lippman, PE
Director of Facilities and Operations
Las Virgenes MWD
4232 Las Virgenes Road
Calabasas, CA 91302

Dear David:

Subject: Evaluation of Blasting Excavation
Proposed 5 MG Tank at Las Virgenes Reservoir

AECOM is very pleased to provide this report, which evaluates how blasting excavation can be performed safely near the Saddle Dam, Spillway, and Main Dam of Las Virgenes Reservoir, for preparing either of the candidate sites for the construction of the 5 MG tank that was recommended by the *2007 Potable Water Master Plan* and the 2009 *Project Alternatives Study for the 1235-ft Backbone Improvements*. Specific issues that are addressed in this report include the effects of blasting on the adjacent dams, the dam abutments, and nearby residences, and any expected concerns of the Division of Safety of Dams (DSOD).

This report is the combined effort of the following team:

- **Gordon Revey** is an independent consultant who specializes in blasting engineering. He has 30 years experience in this field, beginning in mining engineering. He has worked on projects throughout the United States, including many in California. (I worked with Gordon previously on a project in the Lynn Ranch area of Thousand Oaks.) Gordon provided the first half of this report, which focuses on the physics of controlled blasting and the expected effects on structures and people.
- **Tom Blake, CEG, PE** a geotechnical engineer and geologist with Fugro West provided background information, which included his prior study of excavation alternatives at the proposed tank sites. Tom also reviewed Gordon Revey's report in detail.
- **Stan Kline, PE** is an AECOM geotechnical engineer, with experience on dozens of dam and embankment projects, including stability studies for DSOD. Stan has over 30 years of experience. Stan evaluated the expected effects on the dams, based the technical details in Gordon Revey's report, a review of the original design documents for the dam, and a 1993 Woodward Clyde Report that re-analyzed the dam.
- **Doug Yadon, PE** is an AECOM geotechnical engineer, with experience on dozens of dam projects, including several in California. Doug provided a technical quality review of Stan Kline's report.
- **Glen Hille, PE** is an AECOM construction manager with considerable blasting experience. Glen was the resident engineer during construction of the Filter Plant, when blasting was previously performed next to the dam. Glen was consulted regarding this earlier work.

With the exception of Doug Yadon, each of these experts will attend the public workshop on July 30th, to answer questions from the public and Board. Gordon Revey will also provide a brief presentation at the workshop.

The following is a summary of key findings of this report:

1. At either of the proposed tank sites (A or C), the use of blasting is recommended because the bedrock is very hard and has few fractures.
2. Blasting specifications should limit the maximum velocity at the closest residence to no more than 0.5 inches per second. This criterion is to preclude discomfort to occupants. At this level, the excavation activity should be perceptible, but not disturbing.
3. To preclude any damage to nearby structures, the specifications should also limit the maximum velocities to:
   a. No more than 2 inches/second at the dams
   b. No more than 1 inch/second at the Filter Plant and other District buildings
   c. No more than 5 inches/second for buried utilities
4. At Tank Site A, the controlling criterion will be 0.5 inches/second at the closest house, approximately 480 feet away.
5. At Tank Site C, the critical issue is blasting near the spillway for construction of the access road
6. Blasting was performed during the construction of the Three Springs Tract and the Filter Plant in 1988. Appendix A shows that the permit issued by Westlake Village for the tract construction imposed identical velocity limitations for the dam and nearby residents as recommended in Gordon Revey's report.
7. For the Filter Plant in particular, blasting was used near the main dam, for the excavation of approximately 2,200 cubic yards of material. Photos in Appendix A affirm Glen Hille's recollection that the blasting was performed in a controlled fashion without significant incidence.
8. Prior to construction of the Three Springs Tract in 1988, the District concluded that the velocity limitation of 2 inches at the base of the dam was 1/70th of the vibration level expected from the design-level earthquake.

Conclusion: if blasting is performed in a strictly controlled manner conforming to the limitations recommended here, it should not be disturbing to nearby residents, should not damage any structures, and will have no appreciable impact on the safety or performance of the dam.

I hope that this report provides the information the District needs.

Sincerely,

Dan Ellison

Dan Ellison, PE
Project Manager

REVEY Associates, Inc.

Gordon F. Revey
Principal

9250 E. Morning Star Place
Parker, CO 80134-5611
Phone: (303) 470-0416
Fax: (303) 791-0140
Email: grevey@earthlink.net

Revised May 5, 2011

RE: Blasting Evaluation for LVMWD Las Virgenes Water Tank Project

Attention: Messrs. Thomas F. Blake, CEG, GE and Dan Ellison, PE

Tom and Dan:

My evaluation of blasting issues related to the two proposed sites for the Water Tank at the Las Virgenes Dam Site follows. A separate WORD document containing draft blasting specifications for the work is also attached. I have written the specifications so they can apply to both proposed sites.

Introduction and Scope

It is understood that the Las Virgenes Municipal Water District (LVMWD) intends to build a new Water Storage Tank on land adjacent to the existing Las Virgenes Dam in Westlake Village, CA. Preliminary design drawings indicate two potential locations are being considered. These alternative locations A and C are shown in Figure 1.

On March 15, 2011, the author (G F Revey) visited the site to review the proposed tank sites, inspect conditions of the Las Virgenes Dam and adjacent facilities, and the proximity of offsite property. For this evaluation I have reviewed the Preliminary Geotechnical Report prepared by Thomas F. Blake of Fugro West , Inc., dated July 19, 2010; the Las Virgenes Dam Settlement Report by LVMWD (2010), the Westlake Reservoir Site and Laboratory Investigation by W.A. Wahler & Associates (1969), and the as-built Construction Plans for the Westlake Reservoir by Boyle Engineering (1973).

As we discussed during our site visit, I believe the use of controlled blasting methods will almost certainly be required to excavate the hard diabase and agglomerate formations observed at the site. Seismic refraction data and other findings expressed in the Fugro Report also support this conclusion. Moreover, blasting methods were used to quarry similar rock when the dam was constructed in the early 1970’s.

This letter report discusses potential blasting effects and recommended controls. Effects include direct ground fracturing beyond blasting limits, ground vibration, air-overpressure/noise, and flyrock.

General Discussion of Alternative Sites:

Based on all my observations of the site and past experience with similar work, from a blasting perspective, the rock excavation work, including access excavations, could be done safely at both proposed sites. I realize that access and pipeline construction issues will affect the decision too.

Based on the observed conditions of northeast embankment of the reservoir, I believe it would be very difficult to construct an access road to the Alternate C location. Moreover, blasting would be required in the agglomerate rock slope and it would occur very close to concrete spillway structures. These excavations could be done, but the work would be difficult and there would be disturbance to water in the reservoir.

Figure 1 – Las Virgenes Alternate Water Storage Tank Sites

From a blasting perspective, Alternate Site A is closer to residential property. Respective horizontal distances between rock excavations at these sites to the nearest residence are approximately 480 and 1,160 feet. Blasting at distances as close as 817 feet to homes may be needed to excavate the access road to the Alternate C Site.

Blast Effects

When explosive charges detonate in rock, they are designed so that most of the energy is used in breaking and displacing the rock mass. However, some of the energy can also be released in the form of transient stress waves, which in turn cause temporary ground vibration. Detonating charges also create rock movement and release of high-pressure gas, which in turn induce air-overpressure (noise), airborne dust and audible blast noise.

In the very-near zone, crushing usually occurs in the rock around the charge. The extent of this compressive and shear failure zone is usually limited to one or two charge radii (half the diameter of the charge). Beyond the plastic crushing zone, the rock or ground is temporarily deformed by elastic strain waves. For some distance, tangential strain intensity exceeds the rock's strength and new fractures are created. The magnitude of dynamic strain and particle motion decrease as distance from the charge increases. Radial cracks are created in rock around detonating charges as a result of induced strain that exceeds the rock's tensile strength. These cracks generally do not extend farther than 13 charge-diameters into rock remaining around excavations. For instance, if the diameter of the charge is 2 inches, radial cracks might extend 26 (2 x 13) inches into adjacent rock. Direct rupturing or overbreak of rock beyond the desired limits of a blast area might also occur if ground is weak or jointed and/or poor perimeter control methods are used for blasting. The extent of radial fracturing and ground rupturing at the limits of excavations can be reduced significantly by using decoupled charges; whereby the explosive charge diameter is less than the blasthole diameter.

Vibration Ground Waves:

Within and beyond the cracking zone, stress waves spread through the rock mass and along the ground surface. As shown in Figure 2, some waves pass through the "body" of the rock mass. Primary compression waves and shear waves are examples of body waves. Other surface vibration waves travel along the ground surface similar to the way waves travel along the surface of water. In an ideal isotropic and homogenous rock mass, wave energy would travel evenly in all directions. However, most rock masses are far from ideal, so wave energy is reflected, refracted and attenuated by various geological and topographical conditions. The elastic properties of rock greatly influence vibration magnitude and attenuation rate.

When seismic waves pass through the ground, ground particles oscillate within three-dimensional space. Soon after blasting has stopped, vibration energy dissipates and the ground particles become still.

Seismic waves travel through ground and rock at speeds measured in thousands of feet per second. However, the velocity of ground particles disturbed by the passing waves is much less. For instance, passing seismic waves with velocities as high as 10,000 ft/s might typically cause particle motion with velocities ranging from 0.02 to 10 in/s. In other words, the peak particle motion in this case is 12,000 [10,000 / (10/12)] times less than that of the passing seismic wave.

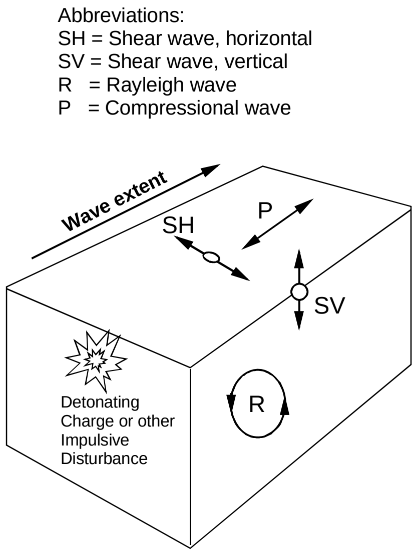


Figure 2 – Typical Vibration Waves

The characteristics of ground motion can be measured in several ways. These measures include:

- Particle displacement
- Particle velocity
- Particle acceleration
- Vibration frequency

Displacement is a measure of ground particle travel distance or location with respect to time. Particle velocity measures the speed of particle movement and acceleration is the rate of velocity change. Vibration frequency is a measure of ground particle oscillations occurring per second of time. Frequency is reported in units of Hertz (Hz), which is equivalent to cycles per second.

Standard industry damage criteria and “safe levels” of ground motion are generally based on particle velocity and frequency of motion. The response of humans to ground motion is primarily influenced by ground motion velocity and duration of the motion. Vibration intensity is expressed as Peak Particle Velocity (PPV) or the maximum particle velocity of the ground. Since ground-shaking speeds are quite low, it is measured in inches (in/s).

Persons not familiar with vibration science often confuse particle velocity values with ground displacement. For instance, if a measured peak particle velocity is 0.25 in/s, the ground has NOT moved 0.25 inches because ground particles disturbed by blast vibration waves will oscillate back and forth many times in a second. This is why frequency of motion is important because, unlike earthquakes where frequency of motion is quite low, cycles of ground particle shaking (frequency) caused by blasting usually occur at 10 to 50 Hz. Since the ground particles are shaking back and forth or up and down so quickly, similar to running in place, they do not move very far. As shown in Figure 3, the intensity and frequency of vibrating ground particles or changes in air-pressure can be determined when these events are measured and plotted with respect to time.

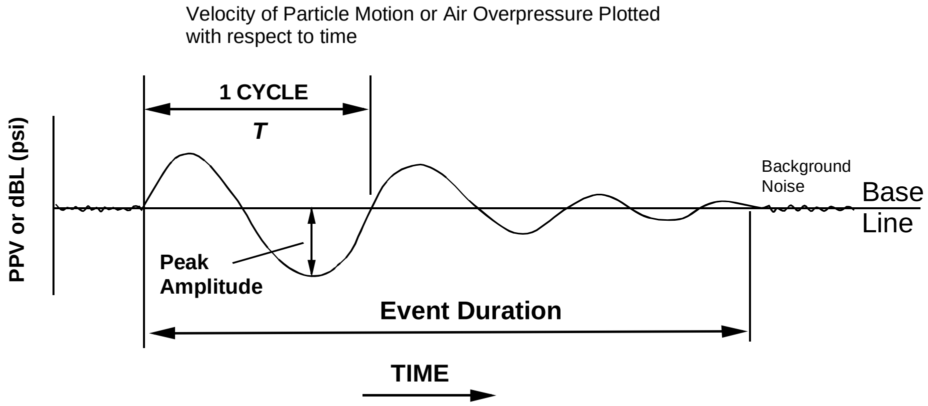


Figure 3 – Idealized Vibration or Air Overpressure Time—Intensity History Plot

Vibration Perception and Damage Criteria:

In Report of Investigations RI 8507, the US Bureau of Mines (Siskind, 1980) recommends safe ground motion limits shown in Figure 4. These limits, ranging from 0.2 to 2.0 in/s, are the basis for most regulatory blast-induced vibration levels in most State and Federal jurisdictions throughout the United States, and are specifically intended to prevent cosmetic crack damage in plaster or drywall in typical wood frame homes.

The lowest flat-response frequency range of velocity transducers used in conventional seismographs is 2 Hz, so most regulations include PPV limits ranging from 0.5 to 2.0 in/s. Moreover, the safe level curve in Figure 4 was extrapolated in the low PPV range because data in RI8507 and authors admissions indicate no actual cosmetic wall damage was found below 0.5 in/s.

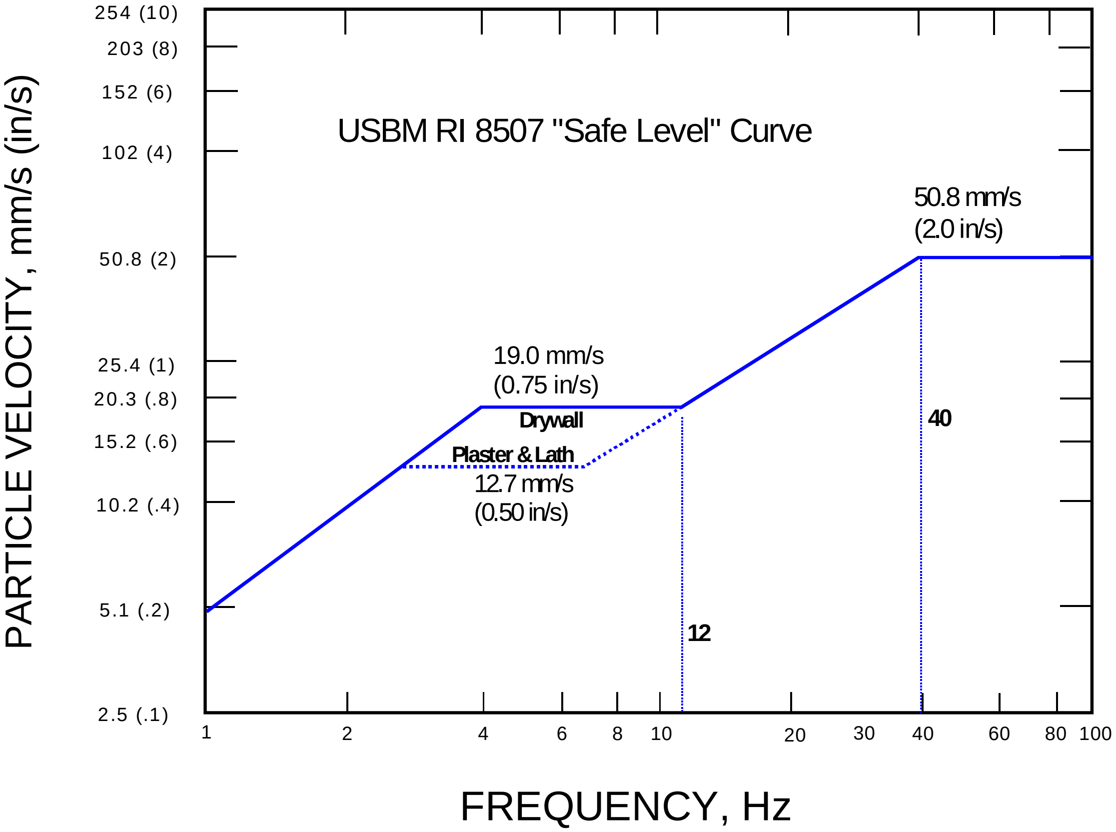


Figure 4 -- USBM “Safe Level” vibration curve from RI 8507

Blast Noise (Air-Overpressure):

The term “blast noise” is misleading because the largest component of blast-induced noise occurs at frequencies below the threshold-of-hearing for humans (16 to 20 Hz). Hence, the common industry term for blast-induced noise is “air-overpressure”. As its name implies, air-overpressure is a measure of the transient pressure changes. These low-intensity pulsating pressure changes, above and below ambient atmospheric pressure, are manifested in the form of acoustic waves traveling through the air. The speed of sound varies in different materials, depending on the density of the medium. For instance, pressure waves travel at the speed of 4,920 ft/s (1,500 m/s) in water, whereas, in air they travel at only 1,100 ft/s (335 m/s) because air has a lower density.

When calculating maximum air-overpressure values, the absolute value of the greatest pressure change is used, regardless of whether it is a positive or negative change. The frequency of the air-overpressure (noise) is determined by measuring how many up-and-down pressure changes occur in one second of time. Blast noise occurs at a broad range of frequencies and the highest-energy blast noise usually occurs at frequencies below that of human hearing (<20 Hz).

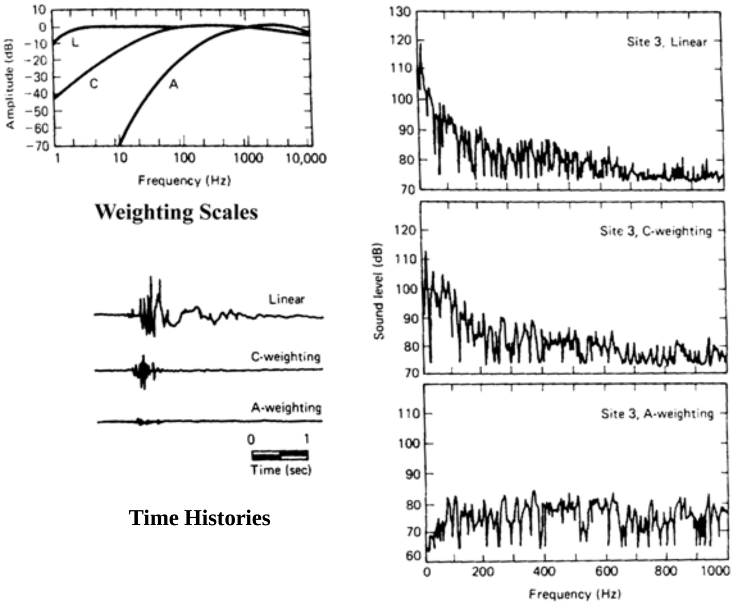
Air-Overpressure Measurement Scales:

Regular acoustical noise measurements taken for the purpose of monitoring compliance with local noise ordinances almost always use A-weighted (dBA) and C-weighted (dBC) scales. Instruments used for these A and C-scale measurements filter out most of the air-overpressure occurring below a frequency of 20 Hz because humans cannot hear it and are generally not annoyed by it. Much of the air-overpressure frequency spectrum created by rock blasting occurs at frequencies below 20 Hz. Accordingly, seismographs used for blasting measurements are equipped with microphones and recording equipment that captures all air-overpressure fluctuations occurring from 2 to 200 Hz. These blasting measurements are called "linear-scale" measurements and the unit designation is “dBL.”

A significant amount of the energy in blast-induced air-pressure waves occurs at frequencies below 20 Hz. Thus, when A-weighted and C-weighted scales are used to record blast-induced noise, much of the event is filtered out and the reported intensity or decibel values are significantly less than what would be recorded by a linear scale 2-Hz-response microphone reporting results in dBL-scale. Differences between decibel scale measurements for individual blasts will vary depending on their unique frequency-intensity spectrums. Since full-range recording of blast-induced noise can only be done with linear (2-Hz response) instruments, it is imperative that all compliance specifications for blast-induced noise be expressed in “Linear” scale decibels (dBL).

In a study by USBM (RI 8485 – Siskind et al, 1980), researchers measured blast-induced noise at a common location using A-weighted, C-weighted and linear microphones. Comparable measurements taken about 800 feet from a blast, as shown in Figure 5, show that a linear peak noise of 120 dBL equates to only 112 dBC and 85 dBA.

Differences for individual blasts will vary depending on their unique frequency-intensity spectrums. Since full-range recording of blast-induced noise can only be done with linear scale instruments, it is imperative that all compliance specifications be expressed in linear scale (dBL).



Weighting Scales

Time Histories

After Siskind and Summers, (1974) **Fourier Frequency Spectra**

Figure 5 -- Effects of Weighted Filtering on Air-overpressure Records

The regulatory limit generally applied in State of California regulations, for air-overpressure measured with 2-Hz response seismographs is 133-dBL (0.0129 psi). For practical comparison, a 20-mph wind gust creates more strain in windows and walls than that caused by air-overpressure of this magnitude. Damage to old or poorly glazed windows does not occur until air-overpressure reaches about 150 dBL. More importantly, since the decibel scale is a logarithmic ratio, the actual air-overpressure at 150 dBL is 0.092 psi, versus 0.0129 psi at 133 dBL. Therefore, the actual air-overpressure at the 133 dBL limit, is over seven times (0.0917/0.0129) lower than the threshold damage level at 150 dBL. The relationship between air-overpressure expressed in psi and decibel-scale measurements are shown in Equation 1.

$$dB = 20\,Log_{10}\left(\frac{P}{P_o}\right) \quad or \quad P = P_o\,10^{\left(\frac{dB}{20}\right)}$$

Equation 1

Where: dB = decibels, P = overpressure (psi), P_o = Threshold of Human Hearing Pressure (20 microPascals or 2.9 x 10^{-9} psi).

NOTE: Due to the logarithmic ratios used to calculate decibel values, seemingly small changes in decibel readings can equate to large changes in absolute air-overpressure (psi). Hence, all relative comparisons should be done in the base psi pressure units.

Blast Vibration Intensity Predictions:

It is standard practice to use scaling relationships to predict vibration intensities at various distances. These relationships, based on similitude theory, are used to develop empirical relationships between ground vibration particle velocity, charge weight, and distance. Distance is scaled by dividing it by the square root of the maximum charge weight firing at any time within a blast. This single scaled distance variable can then be used to predict vibration intensity, which is essentially kinetic energy expressed as Peak Particle Velocity (PPV). The scaling relationship between PPV and scaled distance (D_s) is shown below in Equation 2.

$$PPV = K\left(D \big/ \sqrt{W} \right)^m \qquad or \qquad PPV = K\left(D_s\right)^m \qquad \text{Equation 2}$$

Where: PPV = Peak Particle Velocity (in/s)
D = Distance (ft)
W = Maximum Charge-weight-per-delay (lb)
K = Rock Energy Transfer Constant (K-Factor)
m = Decay Constant
D_s = Scaled Distance (ft-lb$^{-0.5}$)

Site-specific constants, ***K*** and ***m***, can be determined by performing a regression analysis of multiple PPV and D_s data pairs. In simple terms, for any given site, ***K*** is a measure of how much vibration energy is transferred to the ground near the explosive charge and ***m*** defines how fast the energy attenuates with distance.

A sample regression curve developed by the author when evaluating ground vibration impacts at the San Rafael Rock Quarry in Marin County CA is shown in Figure 6. When plotted in log-log scale, the exponential relationship between scaled distance and PPV generally follows a straight line with a negative slope (***m***) ranging from -1.0 to –1.9, and Y-intercept (***K***) values varying between 605 and 24, as defined by Oriard (1970). The ***K*** value (amount of energy at the source) is higher when charges are more confined and/or rock has a high stiffness ratio (modulus of elasticity).

More discussion on this topic is found in the attached technical paper, “Dimensional Similitude and PPV-Overpressure-Strain Predictions,” (Revey, 2011).

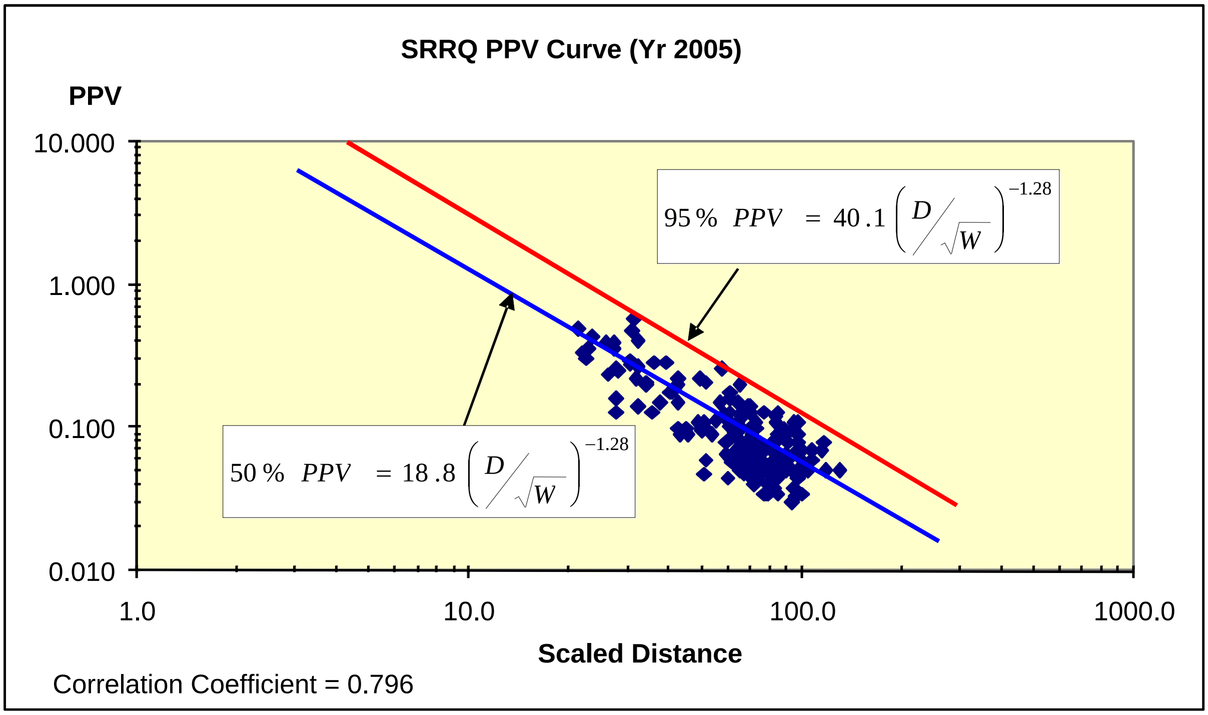


Figure 6 – Vibration attenuation curve for San Rafael Rock Quarry – Marin County, CA

When site-specific historical data are not available, the K factor value can be estimated based on physical rock properties and degree of blast confinement. From the author's past experience, for blasts in hard rock formations like the volcanic rock indicated at the Las Virgenes Dam site, a prediction equation with a ***K***-factor of 240 and attenuation constant of -1.6 can be used to predict vibration intensities (PPV) at various locations of concern. With this cautiously high K-factor, predicted levels of vibration will likely be higher than actual values measured at similar scaled distances. The resulting prediction equation, which is used in the site-specific evaluations in Section 4 of this report, is shown Equation 3 below.

$$PPV = 240\left(D/\sqrt{W}\right)^{-1.6} \qquad \text{Equation 3}$$

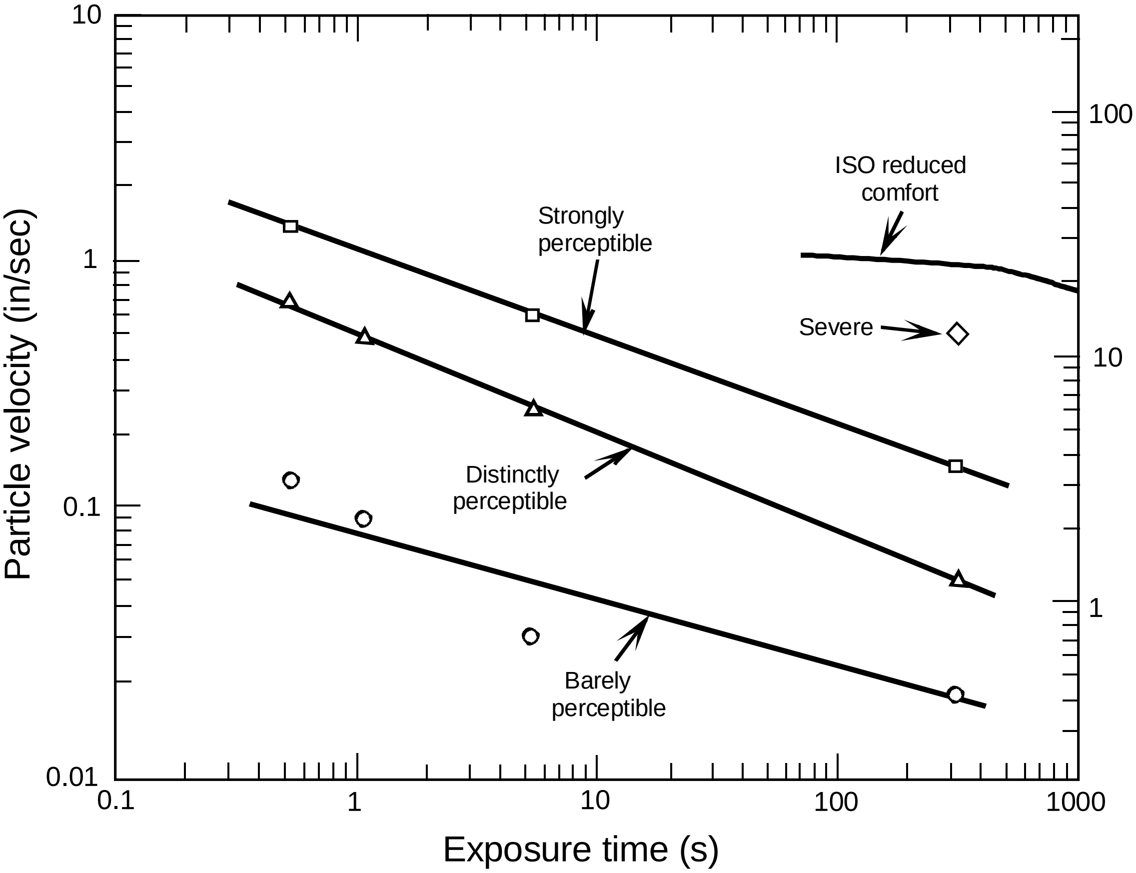
.

Where:

PPV = Peak Particle Velocity (in/s)
D = Distance (ft)
W = Maximum Charge-weight-per-delay (lb)
K = Rock Energy Transfer Constant (K-Factor)
m = Decay Constant
$D_s = (D/W^{1./2}) =$ Scaled Distance (ft-lb$^{-0.5}$)

Human Response to Transient Vibrations:

In addition to concerns about vibration damage, under certain conditions, humans and animals can be startled or annoyed by blast-induced ground vibration. Research has also shown that the human response to transient vibration, like those caused by blasting, varies depending on exposure time and the intensity of the motion. Response curves defining how humans respond to transient vibrations based on these variables are shown in Figure 7.



Human response to transient pulses of varying duration after Wiss and Parmalee (1974)

Figure 7 – Human Response to Transient Vibration

Recommended Vibration and Air-Overpressure Limits

Based on prevailing blast-vibration control practices used in California and throughout the United States, regulators and blasting engineers develop vibration limits that will: 1) prevent damage to structures and utilities and 2) minimize annoyance and complaints from project neighbors.

Residential Buildings:

As shown in Figure 1, the closest home to all sites is 480 feet (Alternative A). Based on human response issues and the author's experience at many blasting operations, it would be wise to plan on limiting PPV at all offsite occupied residential or similar community structures to 0.5 in/s at all frequencies of motion. Despite studies like RI 8507 (Siskind, et al, 1980) that indicate that higher PPV levels are safe when frequency of motion is higher, allowing higher limits is impractical because complaints and community problems would be unacceptable due to human response factors. I have reflected this limitation in the accompanying draft blasting specifications.

Buried Utilities:

It is presumed that pipes and other communication cables are buried in the vicinity of Alternative Site A. In research done by the US Bureau of Mines (RI 9523 – Siskind et al, 1993), it was found that buried pipes of all types of construction can safely withstand peak ground motion of 5.0 in/s. This same standard is also regularly applied to protect buried cables. Since the 0.5-in/s limit at residences will have the greatest influence on blast designs, I have included a more cautionary PPV of 3.0 in/s to protect utilities from blast-induced ground motions in the draft specifications. This limit will have no significant impact on blasting cost or productivity.

LVMWD Site Structures:

All of the structures I observed on the site would experience no harm if PPV is limited to 1.0 in/s at all frequencies of motion.

Las Virgenes Dam:

Blast-induced motion in compacted soils and rock in the Las Virgenes Dam fill zones caused by blasting will occur with shaking frequencies in the 20 to 60 Hz range. With this motion, particles of the compacted earth fill are changing direction so quickly they are effectively running in place. At other projects, the author has applied the standard 4.0-in/s PPV limit used by the US Bureau of Reclamation (Scott, 2008) to protect earthen dams from blast-induced motion. No damage resulted in all cases.

In this case, representatives of California Division of Safety of Dams (DSOD) have requested a limit of 2.0 in/s at the dam. Although this limit is much more than conservative than necessary, it will not increase the costs of the work if applied because the 0.5-in/s limit applied for residential homes will create similar restraints on charge weights.

With a typical frequency of motion of 30 Hz for peak vibration (2.0 in/s or less) at the closest portions of the earthen dam, with sinusoidal motion, peak elastic ground displacement would be around 0.01 inches [PPV / (2 x pi x f)]. Note that vibrating ground particles are not separated by the amount of maximum particle displacement because they are moving together just slightly out of step or phase. For this case where total dynamic particle displacement would be around 0.01 inches, the actual separating strain between the ground particles is orders of magnitude less than the peak displacement. Due to this condition there is not enough differential shearing or tensile displacement to cause any damage or permanent separation.

A 2.0 in/s PPV limit is also adequate to protect other instruments that might be installed in the Dam.

Air-Overpressure Limit:

As described earlier in the technical summary regarding air-overpressure, the regulatory limit generally applied in State of California regulations, for air-overpressure measured with 2-Hz response seismographs is 133-dBL (0.0129 psi). This is a standard safe limit for structures of all types, based on research by the US Bureau of Mines (RI 8485 --Siskind et al, 1980), and I have used it in the draft specifications.

Other Blasting Controls

In the attached draft specifications, in addition to controls for blast-induced vibration and air-overpressure, I have included limitations that will assure the scale of blasting is controlled (holes size and maximum benches). I have included very cautious charge confinement provisions regarding inert stemming and burden confinement. To prevent ammonia and nitrate pollution of reservoir water, I have prohibited the use of ANFO or other flowable explosives that could be spilled to ground. Background information regarding ammonia and nitrates issues and control is provided in an attached paper (Revey, 1995). I have also required the use of blast mat covering for all blasts to assure no excessive movement of blasted rock or debris.

Closing Comments

Additional technical modules that define blast design terms and other related methods described herein accompany this letter report.

From the author’s experience at other projects, the success of the work improved when engineers and inspectors overseeing the work participated in a one-day customized training program covering general blast design, blasting safety, and project-specific concerns. For continuity of purpose, important blasting concerns identified now and addressed in the specifications should be stressed to the inspection staff. Trained inspectors will identify issues sooner and are not at a disadvantage when discussing blasting-compliance issues with blasters.

After the contractor has submitted general blasting plans for review, it is also wise to require and conduct an on-site kickoff meeting to review plans and concerns. Inspectors, geologist/engineers, and managers representing the owner, and the contractor’s blasters and key managers, monitoring specialists, and other stakeholders would attend this one-day session. The contractor would present their general blasting and explosives handling safety plans, followed by discussions regarding unresolved issues. These meetings are also a valuable tool for reducing construction claims related to blasting because they provide a forum for highlighting the challenges of the blasting. A public meeting designed to explain blasting controls and impacts can also be beneficial.

Respectfully submitted,

Gordon Revey

Enclosures:

1) Draft technical specifications for blasting
2) ISEE Industry Blast Monitoring Standards
3) Rock Blasting Design Terms
4) Dimensional Similitude and PPV-Overpressure-Strain Predictions, (Revey, 2011)
5) Practical Methods to Control Explosive Losses and Reduce Ammonia and Nitrate Levels in Mine Water, (Revey, 1995)

Technical References

Hall, S, Fraser, J., Mellen, J. and Shephardson, D.J. (1998). “Response of Zoo Animals to Airblast and Ground Vibration Resulting from Light Rail Train Construction,” Metro Washington Park Zoo, Portland, Oregon, 1998.

Oriard, L.L., (1970). “Blasting Operations in the Urban Environment,” Association of Engineering Geologists Annual Meeting, Washington, DC, October 1970, published in Bulletin of AEG, Vol. IX. No. 1, October, 1972.

Scott, G.A., (2008). DRAFT Position Paper Construction Blasting Vibration Limits, US Bureau of Reclamation, April, 2008.

Siskind. D. E. et al, R.I. 9523, (1993), SURFACE MINE BLASTING NEAR PRESSURIZED TRANSMISSION PIPELINES, Siskind, David E., Stagg, Mark S., Wiegand, John E. and Schultz, David L., 1993.

Revey, G.F., (1995). Practical Methods to Reduce Ammonia and Nitrate Levels in Mine Water, Society of Mining Engineering (SME), Vol. 48, No. 7: 61-64, March, 1995.

Siskind, D.E. and Fumanti, R.R., RI 7901, (1983). BLAST-PRODUCED FRACTURES IN LITHONIA GRANITE, United States Bureau of Mines, Report of Investigations 7901.

Siskind, D. E., Stagg, M. S., Kopp, J.W. and Dowding, C.H. (1980). Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting. RI 8507, U. S. Bureau of Mines.

Siskind, D.E., Stachura, V.J., Stagg, M.S., and Kopp, J.W., (1980). Structure Response and Damage for Airblast from Surface Mining, US Bureau of Mines Report of Investigations 8485.

Wiss, J.F. and Parmalee, R.A. (1974), "Human Perception of Transient Vibrations," Journal of the Structural Division, ASCE, Vol. 4, pp. 349-377.

Revey Report Enclosures

1. Draft Technical Specifications for Blasting
2. ISEE Industry Blast Monitoring Standards
3. Rock Blasting Design Terms
4. Dimensional Similitude and PPV – Overpressure – Strain Predictions, (Revey, 2011)
5. Practical Methods to Control Explosive Losses and Reduce Ammonia and Nitrate Levels in Mine Water, (Revey, 1995)

SECTION XXXXX
BLASTING

PART 1 GENERAL

1.1 WORK INCLUDES

A. Rock blasting necessary for miscellaneous facilities, including: tanks, pipe and utility trenches, miscellaneous structure foundations, site drainage and permanent access roads.

1.2 REFERENCES

A. The Contractor shall comply with the applicable rules, regulations and standards established by the Regulatory Agencies, codes and professional societies listed herein, including rules and regulations for storage, transportation, and use of explosives. These rules and standards include but are not limited to the following:

1. The Federal Occupational Safety and Health Act of 1970 and the Construction Safety Act of 1969, as amended.
2. OSHA of 1970, 29 U.S.C., Section 651 et seq., including safety and health regulations for construction.
3. CFR 27, U.S. Department of Justice, Alcohol, Tobacco, Firearms and Explosives Division (ATF). 27 CFR Part 555, Implementation of the Safe Explosives Act, Title XI, Subtitle C of Public Law 107-296; Interim Final Rule.
4. Organized Crime Control Act of 1970, Title XI, Public Law 91-452, approved October 15, 1970, as amended.
5. CFR 49, Parts 100-177 (DOT RSPA); 301-399 (DOT FHA).
6. California Code of Regulations (CCR)
   a. Title 8, Chapter 4, Subchapter 20, Tunnel Safety Orders
   b. Title 8, General Industry Safety Orders, Subchapter 7, Group 18. Explosives and Pyrotechnics
7. Non-regulating Industry Support Organizations
   a. Vibration Subcommittee of the International Society of Explosive Engineers (ISEE), blast monitoring equipment operation standards (1999 or later version if available).
   b. IME (Institute of Makers of Explosives) Safety Library Publications (SLPs).

1.3 DEFINITIONS

1. Air-overpressure – absolute value of increases or reductions to atmospheric pressure measured with a 2-Hz flat-response microphone and expressed in decibels or psi.

2. Blaster-in-Charge or Blasting Supervisor - The single designated and licensed person with complete responsibility and total authority over all decisions involving safe handling, use and on-site security of explosives.

3. Charge-per-Delay - For vibration control, any charges firing within any 8-millisecond time period are considered to have a cumulative effect on vibration and air-overpressure effects. Therefore, the maximum charge-per-delay (W) is the sum of the weight of all charges firing within any 8-millisecond time period. For example, if two 100-lb. Charges fire at 100 ms and one 115-lb charge fires at 105 ms, the maximum charge per delay would be 315 lbs.

4. Controlled Blasting – Excavation of rock using explosives, wherein the blast is carefully designed and controlled to provide a distribution of charge and confining stemming that will excavate the rock to the required limits but minimize overbreak, control rock movement, and assure that intensities of blast-induced vibration and air-overpressure do not exceed regulated or specified limits.

5. Delay-Decked-Charge – Multiple charges with differing firing times placed within a single blasthole that are separated by inert stemming material.

6. Line Drilling - A method of overbreak control in which a series of very closely spaced holes is drilled at the perimeter of the excavation. These holes are not loaded with explosives.

7. Occupied Building - Structure on or off construction limits that is occupied by humans or livestock.

6. Over-excavation – Excavation beyond the neat lines shown on the Drawings.

7. Peak Particle Velocity - Peak Particle Velocity (PPV): The maximum of the three ground vibration velocities measured in the vertical, longitudinal and transverse directions. PPV measurement units are expressed in inches per second (ips).

8. Pre-splitting - A drilling and blasting technique wherein small diameter holes are drilled on close-spacing along the neat excavation lines. The charges are small in diameter, specially prepared for pre-splitting, and are detonated ahead of the main production charges. This technique requires free relief of the perimeter and may require advance excavation of the production area to provide that relief.

9. Primary Initiation - The method used to initiate a blast(s) from a remote and safe location. Primary initiation systems use shock-tubes or electrical current to convey firing energy from the point of initiation to blast locations.

10. Production Holes - Blast holes in the main body of the rock mass being removed by drilling and blasting.

11. Prohibited Persons - Persons prohibited from handling or possessing explosive materials as defined by the seven categories described in Section 555.11 of 27 CFR (ATF Rules).

12. Scaled Distance: A calculated value describing relative vibration energy based on distance and charge-per-delay. For ground vibration control and prediction purposes, Scaled Distance (Ds) is obtained by dividing the distance of concern (D) by the square root of the charge-per-delay (W); so $Ds = D/W^{1/2}$ or when a minimum defined scaled distance is defined to limit charge weight, $W = (D/Ds)^2$. For example, if a blast is designed to meet a minimum scaled distance of 60, the maximum charge-per-delay for a blast located 600 feet from the structure of concern would be $(600/60)^2$, or 100 pounds.

13. Seismograph – An instrument used to record the intensity and frequency of ground vibrations measured with three mutually perpendicular geophones and a linear-scale microphone that measures air-overpressure.

1.4 SUBMITTALS

A. Administrative

1. Blasting Licenses and Permits:
   a. Copy of CalOSHA Blasting Licenses with Construction and Non-electric initiation system endorsements for all proposed blasters-in-charge.
   b. Copies of all blasting permits required by Los Angeles County.
   c. Copy of Blasting CONTRACTOR’s federal ATF License.

2. Conceptual Blasting Plan. Submit at least 30 days prior to start of blasting:

   a. General blasting methods that are expected to be used for rock excavation.
   b. Description of blasting techniques as well as techniques to control noise, blasting vibrations, air-overpressures, and fly rock.
   c. Procedures to monitor blast-induced vibrations and air-overpressures at adjacent foundation areas, existing or previously completed structures, and other existing facilities.

    d. Name and qualifications of the person(s) responsible for monitoring and reporting blast vibrations.
    e. Detailed description of clearing, guarding and warning signals that will be applied to assure that no persons or visible wildlife will be in areas where any harm could be caused by blasting operations.
    f. Provide a general sequence and schedule of planned blasting work including lift heights, the general sequence of drilling, blasting, and excavating.
    g. Include details of a test blast using no more than 60% of the maximum expected charge-per-delay.

3. Blasting Safety Plan

    a. A complete description of the clearing and guarding procedures that will be employed to ensure personnel, staff, visitors, and all other persons are at safe locations during blasting. This information shall include details regarding visible warning signs or flags, audible warning signals, method of determining blast area zones, access blocking methods, guard placement and guard release procedures, primary initiation method, and the system by which the blaster-in-charge will communicate with site security guards.

    b. Detailed description of how explosives will be safely transported and used at the various work sites. Plans shall explain how day-storage boxes and explosive transport vehicles will satisfy all applicable regulations. This plan shall also indicate how explosives will be inventoried, secured and guarded to prevent theft or unauthorized use of explosives.

    c. Include Material Safety Data Sheets (MSDS) and specific details about hazard communication programs for employees.

    d. Equipment that will be used to monitor the approach of lightning storms and in the event of such, evacuation and site safety security plans.

    e. Contingency plans for handling of misfires caused by cut-offs or other causes.

    f. Fire prevention plan details, including smoking policies, procedures and limitations for work involving any open flames or sparks, description and location of all fire-fighting equipment, and fire fighting and evacuation plans.

    g. Initial and ongoing blasting and fire safety training programs.

    h. Description of the personal protective equipment that will be used by the Contractor's personnel, including but not limited to, safety glasses, hard-toe footwear, hard hats and gloves.

   i. Obtain copies of all applicable codes, regulations and ordinances, keep a copy in project files at all times, and provide LVMWD's Representative with a copy. The Contractor's Safety Representative shall ensure that ongoing blasting work complies with all applicable regulations.

4. Qualifications:

   a. Submit names of all proposed Blasters-in-Charge and include experience summaries documenting they have a minimum of 10 years of construction blasting experience at projects with similar blasting conditions. Include references for each proposed Blaster-in-Charge from representatives of at least three owners at projects of a similar nature.

   b. Submit qualifications of proposed Blasting Consultant in conformance with Part 1.5.B.

   c. Submit qualifications of proposed Property Condition Survey Professional in conformance with Part 1.5.C.

5. At least 20 days before surveys are done, submit name and qualifications of the independent Professional or firm proposed to conduct pre-blast condition survey(s), including a list of references.

6. Blast Monitoring Equipment – Details of instrumentation to be used to monitor vibrations and air-overpressure levels complete with performance specifications and user's manuals supplied by the manufacturer. Also submit copies of calibration certificates from the equipment maker certifying that microphones, geophones and all recording equipment has been calibrated within 12 months of the time it will be used.

7. Submit three copies of all pre-blasting reports including photographs and video in DVD format to LVMWD'S Representative at least 10 calendar days before any blasting occurs. The surveys shall be repeated at the conclusion of blasting, and three copies of the post-blasting reports shall be delivered to LVMWD'S Representative seven calendar days after completion of all basting activities.

B. Blasting Records:

1. Individual Shot Plans at least 48 hours prior to the proposed time of each blast, showing:

   a. Sketches showing number, location, diameter, depth, inclination of drill holes.
   b. Sketches showing amount, type and distribution of explosive per hole; and type and quantity of stemming used to confine all blast charges.

c. Pounds of explosive per square foot for wall-control blasting.
d. Powder factor (lb/yd^3) for production blasting.
e. Delay timing pattern showing initiation hookup and firing times for all separate charges.
f. Maximum charge-per-delay, distance to nearest structures of concern, including scaled distances and calculations of maximum expected peak particle velocity.

2. Blast Monitoring Records: Submit the following within 24 hours after all blasts:

   a. A copy of the instrument-software generated blast monitoring report at each instrument location that includes measured peak particle velocity in inches per second, peak air-overpressure in linear-scale decibels and vibration and air-overpressure event plots, date and time of event recording, and date the instrument was last calibrated.
   b. Scaled map showing the locations of all blast monitoring instruments.

3. Blast Reports: Submit the following within 24 hours after all blasts:

   a. Submit blast report showing actual charge delay timing details showing surface and in-hole firing times of all initiators, summaries of all explosives and initiators used, maximum charge-per-delay, hole diameters, spacing, depths, burden, and hole charging and stemming configuration of typical holes. Also include all information required by State of California CalOSHA regulations.

C. Approval by LVMWD'S Representative of the Conceptual Blasting Plan and Individual Shot Plans proposed by CONTRACTOR will only be with respect to the basic principles and methods that CONTRACTOR intends to employ. Approval by LVMWD'S Representative does not relieve CONTRACTOR of sole responsibility and liability for the safety of persons and property.

1.5 QUALITY CONTROL

A. All Blasters-in-charge shall be properly licensed and have a minimum of ten years of construction blasting experience at projects with similar scope and complexity.

B. Retain the services of an experienced blasting consultant with at least 10 years experience in developing and overseeing successful close-in blasting work for similar construction projects. All blasting plans, test blasting plans and revisions shall be prepared by or reviewed by and covered with a signed review letter by the blasting consultant. The blasting consultant will not be required to sign the individual blast plans provided they are signed by an on-site licensed blaster. The Blasting Consultant must not be an employee of any Contractors or associated companies of Contractors involved in the work.

C. The independent professional performing the pre-blast condition surveys shall have at least 5 years of documented experience in performing surveys of structures at dams and other heavy civil structures. The survey professional must also be a completely independent third party who is not be an employee of the Contractor, associated companies, or any suppliers to the work.

1.6 BLASTING SAFETY AND EXPLOSIVES SECURITY

A. Comply with all applicable federal, state and local regulations.

B. Protect the safety of all persons and wildlife; and protect all property during blasting operations.

C. Explosives Security: The responsible CONTRACTOR holding the ATF license for this work shall ensure the security of explosive materials at all times when explosive materials are used or kept on the project site and the CONTRACTOR shall ensure that:

1. All persons that handle explosive materials, have control over them, or access to them, must not be prohibited persons, as defined in Section 555.11 of 27 CFR (ATF Rules).

2. All blasting work and explosive handling activities are done under the direct supervision of a properly licensed Blaster-in-Charge.

3. When explosives are delivered to the work sites, they must not be unloaded from delivery vehicles until a responsible blaster-in-charge has signed the delivery paperwork and assumes full authority and responsibility for the security of the explosive materials. Unused explosive materials must be similarly signed over to a properly licensed driver with a Commercial Drivers License with a Hazmat endorsement before explosive materials are loaded onto a fully-DOT-compliant vehicle for removal from the site.

4. The CONTRACTOR shall maintain copies of ATF Employee Possessor questionnaire forms (OMB No. 1140-0072) or documentation of ATF clearance on the CONTRACTOR’s ATF license for all employees who will possess, handle or have access or control over explosives for this work as defined in 27 CFR Part 555. This documentation must be available upon request by the appropriate authorities or LVMWD’S Representative. CONTRACTOR and subcontractor employees, without submitted evidence of satisfactory ATF clearance, must not handle, control or have access to explosive materials.

1.7 EXPLOSIVE STORAGE

A. No explosives shall be stored overnight on site.

1.8 PRE-BLAST CONDITION SURVEY

A. Prior to any blasting, perform a pre-blast survey of the conditions of the Las Virgenes Dam and any other facilities designated by LVMWD's Representative. The pre-blast survey shall include a photographic record of all visible and accessible facilities within 1,000 feet of the blast area.

B. Survey the interior and exterior conditions of all residential property and associated structures located within 1,000 feet of blasting areas. If owner's refuse surveys, provide copies of certified-mail letters documenting attempts to provide the survey by a third-party professional survey company.

C. Type written reports shall include a description of the interior and exterior condition of the various structures examined. Descriptions shall include the locations of any cracks, damage, or other existing defects and shall include information needed to identify and describe the defect, if any, and to evaluate the construction operations on the defect.

D. Reports shall include hard copy color photographs sized at least 4 x 6 inches, printed in glossy format on paper designed for color photo images. If digital cameras are used, resolution of images shall be 5 megapixels or greater. Photos must be taken of all cracks and other damaged, weathered or otherwise deteriorated structural conditions. If necessary, macro lenses and flash illumination shall be used to ensure defects are shown clearly in the photographs. Photos shall contain an accurate date stamp.

E. Structure condition surveys shall be repeated at facilities or properties where damage concerns have been expressed. Details of any observed changes to surveyed structures and documenting photos shall be reported and submitted as required. All reports shall be type written.

1.10 SEQUENCING, SCHEDULING AND NOTIFICATION

A. Provide notification to LVMWD'S Representative at least 24 hours in advance of each blast.

PART 2 PRODUCTS

2.1 ALLOWABLE EXPLOSIVE MATERIALS AND INITIATORS

A. Only fixed cartridge explosives shall be used for blasting. Use of flowable explosives including ANFO or bulk emulsion is prohibited.

B. Only non-electric initiation systems shall be used for blasting.

C. Use of cap and fuse is prohibited.

PART 3 EXECUTION

3.1 BLASTING

A. All explosive charges shall be stemmed with clean washed angular crushed stone sized from 3/8 to 3/4 inches. The amount of stemming shall be at least 25-charge-diameters. For instance, if charge diameter is 2 inches, minimum stemming is 50 inches or 4.2 feet.

B. The diameter of explosive charges shall not exceed 2.0 inches.

C. The minimum confining burden on all explosive charges with exposure to open rock or ground surfaces shall be at least 25-charge-diameters.

D. All blasts shall be covered with woven steel cable or steel-cable and rubber-tire blasting mats. Woven polypropylene or similar weed-barrier fabric, covered with at least6 inches of soil or sand shall be placed over blast areas to protect initiators before mats are placed. Mats shall be overlapped at least 3 feet and shall completely cover the blast area and extend at least three feet beyond the blast area in all directions. If any flyrock or blasted material is thrown more than 10 feet or half the distance to the nearest structure, whichever is less, blasting shall be suspended until LVMWD’s Representative has approved the Contractor's revised blasting plan showing revisions to the procedure adequate to reduce the flyrock.

E. The depth of blasted rock benches, excluding 2-feet of sub-drilling, shall not exceed 15 feet.

F. Perform blasting Monday through Friday only between the hours of 8:00 a.m. and 5:00 p.m. only.

G. The Peak Particle Velocity (PPV) limits shall not exceed:

1. 2.0 in/s at Dam Embankments..
2. 5.0 in/s at buried utilities.

3. 0.5 in/s at residential structures.

H. Scaled distance to nearest residential property shall be 65 or greater.

I. Intensity of air-overpressure at any off-site structures shall not exceed 133 decibels (0.01295 psi).

J. The diameter of holes drilled in rock for blasting shall not exceed 6.5 inches.

K. If specified vibration limits are exceeded, blasting operations shall cease immediately and a revised blasting plan shall be submitted to LVMWD'S Representative. Blasting shall not resume until a revised blasting plan has been reviewed by the ENGINNER and the LVMWD'S Representative has expressed in writing the conditions that will be applied to further blasting work.

L. After a blast has been fired, the Blaster-in-Charge shall inspect the area to determine that all charges have fired as planned and that no hazards exist in the blast area before the all clear signal is sounded and workers and others are allowed to return to the area.

3.2 BLAST MONITORING

A. Blast Monitoring

1. The CONTRACTOR shall provide a minimum of three seismographs for monitoring peak ground vibration and air-overpressure. The equipment and its use shall conform fully to the standards developed by the Vibration Section of the International Society of Explosive Engineers (ISEE).

2. For all blasts, monitor ground motion and air-overpressure at the nearest abutment of the existing dam and at two other locations designated by LVMWD'S Representative. At least three locations shall be monitored for each blast and LVMWD'S Representative may require the CONTRACTOR to monitor at other locations if complaints or other issues arise.

3. Minimum trigger levels for monitoring shall be 0.05 in/s for ground motion and 120 dB for air-overpressure. Trigger level may be adjusted to higher levels if authorized by LVMWD'S Representative.

3.3 TEST BLAST

A. At the start of blasting, perform at least two test blasts to establish that rock movement is adequately controlled and intensities of specified ground motion and air-overpressure are in conformance with specified levels. The scaled distance to the nearest residential property for the test blasts must be 75 or greater.

3.4 REPAIR OF DAMAGE

A. When blasting operations damage offsite properties, or a portion of the work, or material surrounding or supporting the work, the Contractor shall promptly repair or replace damaged items to the condition that existed prior to the damage, to the satisfaction of LVMWD’s Representative.

3.5 SUSPENSION OF BLASTING

A. Blasting operations may be suspended by LVMWD’s Representative for any of the following reasons:
   1. Contractor's safety precautions are inadequate.
   2. Ground motion vibration levels exceed specified limits of maximum particle velocity or maximum particle displacement.
   3. Air-overpressure levels exceed specified limits.
   4. Existing structural conditions are aggravated or adjacent improvements are damaged as a result of blasting.
   5. Blasting endangers the stability or causes damage to rock outside the prescribed limits of excavation.
   6. The results of the blasting, in the opinion of LVMWD’s Representative, are not satisfactory.

B. Blasting operations shall not resume until LVMWD’s Representative has approved the Contractor's revised blasting plan providing modifications to correct the conditions that resulted in the suspension.

END OF SECTION

ISEE INDUSTRY BLAST MONITORING STANDARDS

The following standards should be applied when measuring blast-induced vibration and air-overpressure (noise). These standards are based on the best practices recommended by The Vibration Section of the International Society of Explosives Engineers– 1999.

Part 1. General Guidelines

1. Operators: Only personnel who have successfully completed a proper training course should operate monitoring equipment.

2. Calibration: The instrument manufacturer should annually calibrate recording units and sensors. Documenting certificates should be kept on file and copies should be provided to appropriate persons upon request.

3. Event Record Keeping: Hard copy reports and electronic file-copies of all event-monitoring records should be maintained for all blasts. Operating notes should be programmed into the instruments, which should be printed monitoring records. These notes at a minimum should include the operator’s name, date, time, place and other pertinent data specific to the monitoring location.

4. Trigger Levels: When employing instruments to operate in auto-trigger-mode, trigger levels should be set low enough to record blast effects. If expected levels of blast noise or vibration do not exceed minimum trigger levels, the instrument should be attended by an operator and turned on manually.

5. Documenting Monitor Location: In addition to event reports, an accurate method should be used to determine the monitoring location for later reference. Acceptable methods are 1) plotting numbered locations on scaled maps; 2) defining location with GPS northing, easting and elevation values; and 3) noting the name of the structure and the measured distance (+/- 1 ft) where the seismograph was placed relative to at least two identifiable reference points. Any person should be able to locate and identify the exact monitoring location at a future date.

6. Distance to Blast: The horizontal distance from the seismograph to the blast should be known to at least two significant digits. For example, a blast within 1000 feet would be nearest tens of feet and a blast within 10,000 feet would be measured to the nearest hundreds of feet. Where the vertical-to-horizontal ground slope ratio exceeds 2.5 to1, slant distances or true distance should be used and recorded in the monitoring records.

7. Processing Time: When instruments are used in auto-trigger and continuous-recording mode to record the effects of multiple blasts, the time between successive blasts shall be at least one (1) minute and seismographs shall be set to NOT automatically print out event records. These procedures should ensure that instruments have adequate time to save event data for each blast and reset to monitoring mode before subsequent blasts occur.

8. Memory Management: The instrument operator should know the memory or record capacity of the seismograph and ensure that adequate memory is available to store the event data from the blast(s) planned during that operating day.

9. Waveform Data: Instruments shall be set to save full waveform data for all monitored blast and digitally saved event files shall contain this data for use in further analyses if needed.

10. Instrument Setup Time: Equipment operators should allow ample time for proper setup of the seismograph, transducers and microphones. At least 15 minutes of time should be allotted for each setup location.

11. Securing cables: In order to prevent false triggering caused by wind-blown cables, the operator should secure suspended or freely moving cables from the wind or other extraneous sources.

Part II. Ground Vibration Monitoring

A. Sensor Placement

The sensor should be placed on or in the ground on the side of the structure towards the blast. A structure can be a house, pipeline, telephone pole, etc. Measurements on driveways, walkways, and slabs are to be avoided where possible.

1. Location relative to the structure: The sensor should be placed within 10 feet of the structure or less than 10% of the distance from the blast, whichever is less.

2. Soil density evaluation: The operator should avoid placing velocity transducers in loose or low-density soils. The density of the ground should be greater than or equal to the sensor density.

3. Sensor Level: Transducers should be placed so they are level or nearly level.

4. Sensor Orientation: Sensor blocks should be oriented so the arrow indicating the longitudinal direction is aimed at the blast location.

5. Monitoring when Access to Nearest Structure is not Accessible: Where access to a structure is not available, the transducers should placed at the accessible location closest the structure of concern and in line with the blast.

B. Sensor coupling

1. Sensor Coupling Methods: Based on expected acceleration determined from Chart 1, to avoid decoupling errors, the operator shall use the following methods to couple vibration transducers to the ground or structure.

    a. Less than 0.2 g: No burial or attachment is necessary.

  b. Between 0.2 and 1.0 g: Transducer should be attached to the ground with a spike or covered with a sand bag.
  c. Greater than 1.0 g: Transducer should be buried, bonded to the ground or structure with stiff clay or putty, or some other method that should achieve firm attachment.

TABLE 1 – Acceleration intensity (g's) based on estimated particle velocities and frequencies

			Maximum Frequency (Hz or cycles-per-second)								
	4	10	15	20	25	30	40	50	100	150	200
PPV (in/s) at Acc. (g) ≥ **0.2**	3.08	1.23	0.82	0.62	0.49	0.41	0.31	0.25	0.12	0.08	0.06
PPV (in/s) at Acc. (g) ≥ **1.0**	15.38	6.15	4.10	3.08	2.46	2.05	1.54	1.23	0.62	0.41	0.31

2. Sensor Burial: When velocity transducers are buried the operator should employ the following methods.

   a. Excavate a hole that is no less than three times the height of the sensor (ANSI S2.47-1990, R1997).
   b. If possible, spike the sensor to the bottom of the hole.
   c. Firmly compact soil around and over the sensor.

3. Attaching Sensors to bedrock or hard Structural Surfaces:

   a. Bolt, clamp or use epoxy or putty to firmly couple the sensor to the hard surface.
   b. The sensor may be attached to the foundation of the structure if it is located within +/- 1-foot of ground level (USBM RI 8969). This should only be used if burial, spiking or and bagging is not practical.

4. Other sensor placement methods: Use other methods as described below if disturbance of the ground is not possible.

   a. Cover transducers with sand bags loosely filled with about 10 pounds of sand. When placed over the sensor the sandbag profile should be as low and wide as possible with a maximum amount of firm contact with the ground.
   b. A combination of both spiking and sandbagging gives even greater assurance that good coupling is obtained.

C. Programming considerations

Site conditions dictate certain actions when programming the seismograph.

1. Ground motion trigger level: The PPV-trigger-level should be programmed low enough to trigger the unit from blast vibrations and high enough to minimize the occurrence of false events. The level should be slightly above the expected background vibrations for the area. A good starting level is 0.05 in/s.

2. Dynamic range and resolution: If PPV is expected to exceed 10 in/s or frequency is expected to exceed 250 Hz, special sensors approved by the Vibration Specialist should be used to measure blast effects. In these cases, the Vibration Specialist should also determine a digital sampling rate that should provide accurate recordings.

3. Recording duration: Set the record time for 2 seconds longer than the blast duration plus 1 second for each 1100 feet from the blast.

Part III Air-overpressure Monitoring

The following procedures should be used as possible when setting up instruments to measure blast-induced noise.

A. Microphone placement

The microphone should be placed along the side of the structure nearest the blast.

1. The microphone should be covered with a windscreen and mounted near the velocity transducers.

2. The preferred microphone height is 3 feet above the ground or within 1.2 inches of the ground. Other heights may be acceptable for practical reasons. (ANSI S12.18-1994, ANSI S12.9-1992/Part2) (USBM RI 8508)

3. If practical, the microphone should not be shielded from the blast by nearby buildings, vehicles or other large barriers. If such shielding cannot be avoided, the horizontal distance between the microphone and shielding object should be greater than the height of the shielding object above the microphone.

4. If placed too close to a structure, the airblast may reflect from the house surface and record higher amplitudes. Structure response noise may also be recorded. Placing the microphone near a corner of the structure can minimize reflection of over-pressure energy. (RI 8508)

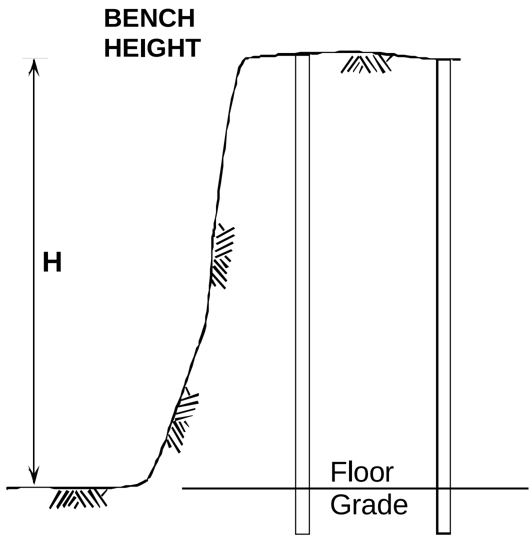
B. Programming considerations

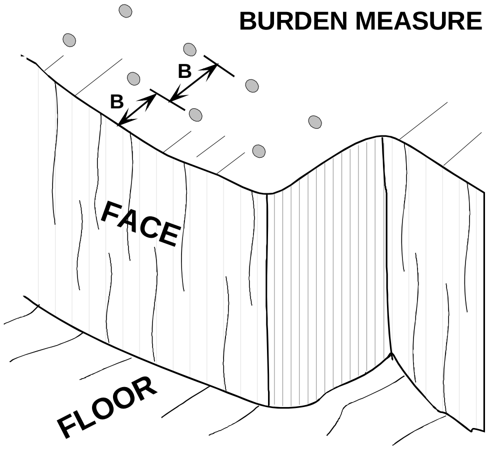
Site conditions dictate certain actions when programming the seismograph to record air-overpressure.

1. Trigger level: When only an airblast measurement is desired, the trigger level should be low enough to trigger the unit from the airblast and high enough to minimize the occurrence of false events. The level should be slightly above the expected background noise for the area. A good starting level is 120 dB.
2. Recording duration: When only recording airblast, set the recording time for at least 2 seconds more than the blast duration. When ground vibrations and air-overpressure measurements are desired on the same record, follow the guidelines for ground vibration programming (Part II C.3).

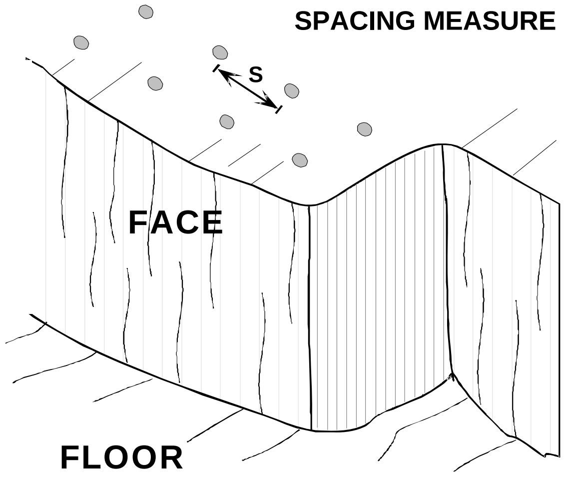
ROCK BLASTING DESIGN TERMS

Bench Height (H): is the vertical height of a rock wall or bench measured from the designed excavation floor or grade level to the top surface or crest of the rock bench.



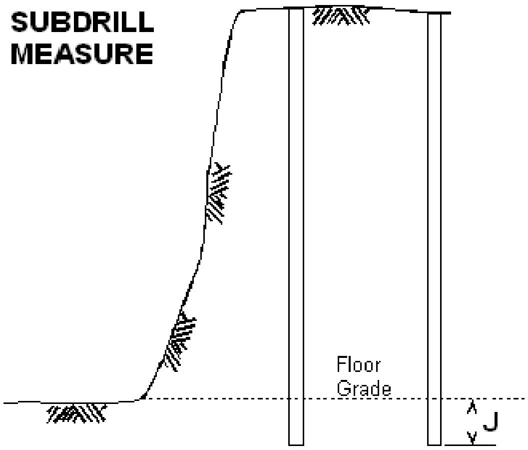


Burden (B): a broadly used term that generally defines the amount of rock between explosive charges and the nearest rock face or wall. Burden is the perpendicular distance measured between rows of blastholes drilled parallel to the longest open bench face. For adequate relief, Burden (B) should be least 2 times the Bench Height (H). For adequate confinement and rock breakage, Burden (B) is generally 20 to 30 times the diameter of the explosive charge.

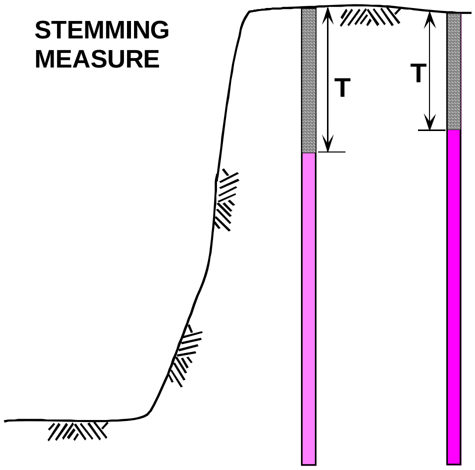


Spacing (S): is generally the distance measured between holes within rows of holes parallel to the major free face. Spacing (S) is generally 1.0 to 1.8 x Burden (B).

ROCK BLASTING DESIGN TERMS, Continued

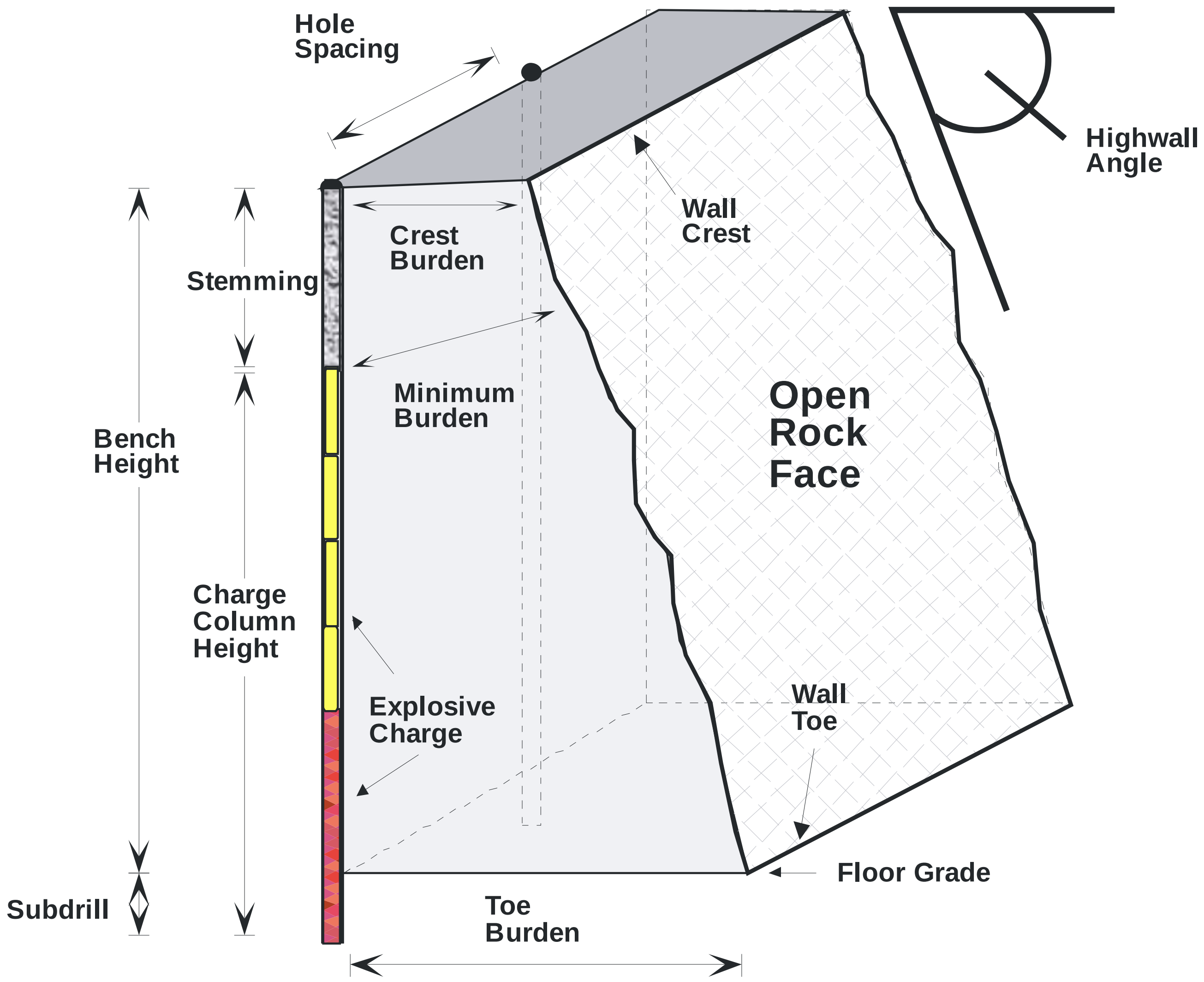


Subdrill (J)**:** is the portion of blastholes drilled below the desired floor or grade elevation of the bench or rock that will be excavated after blasting. High spots of unbroken rock occur between the bottoms of blasted holes so explosive must be placed below the desired floor grade to allow complete excavation at that level. Minimum amount of Subdrilling (J) is generally 2.0 ft (0.7 m). When blasting is done against final horizontal rock surfaces including benches, foundation floors and spillways, no Subdrilling should be done to avoid rupture damage beyond the desired limits of the excavation.

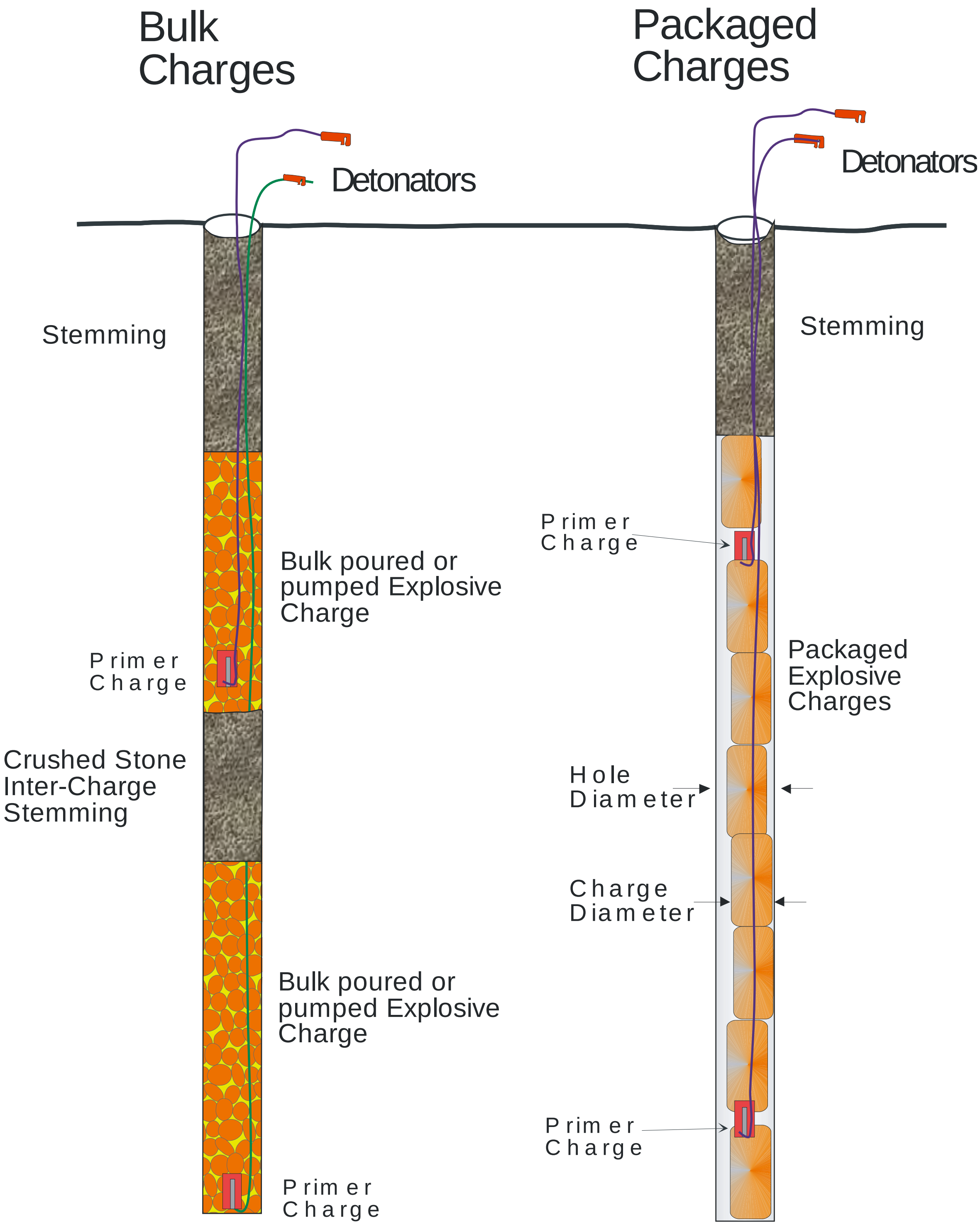


Stemming (T): is inert material placed in the collars of blastholes to confine explosive charges. Clean crushed stone is the most effective stemming material. Good charge confinement results when stemming (T) is at least 20 charge-diameters.

ROCK BLASTING DESIGN TERMS, Continued



ROCK BLASTING DESIGN TERMS, Continued



Not to Scale

ROCK BLASTING DESIGN TERMS, Continued

Powder Factor (PF):

Powder factors are relative measures of how much explosive energy is available to break a fixed quantity of rock. Explosive quantities are normally expressed in units of weight measured in either kilograms (kg) or pounds force (lb). Rock quantities can be expressed in units of weight or volume. When operations measure blasted rock in tons or metric tonnes, powder factors are normally expressed by ratios of explosive weight per ton or tonne. Quarries and mines express their production figures by tons or tonnes, so they calculate powder factors as:

$$\frac{\text{Explosive weight}}{\text{Unit rock weight}} \quad \text{in units of} \quad (\text{kg/tonne}) \text{ or } (\text{lb/ton})$$

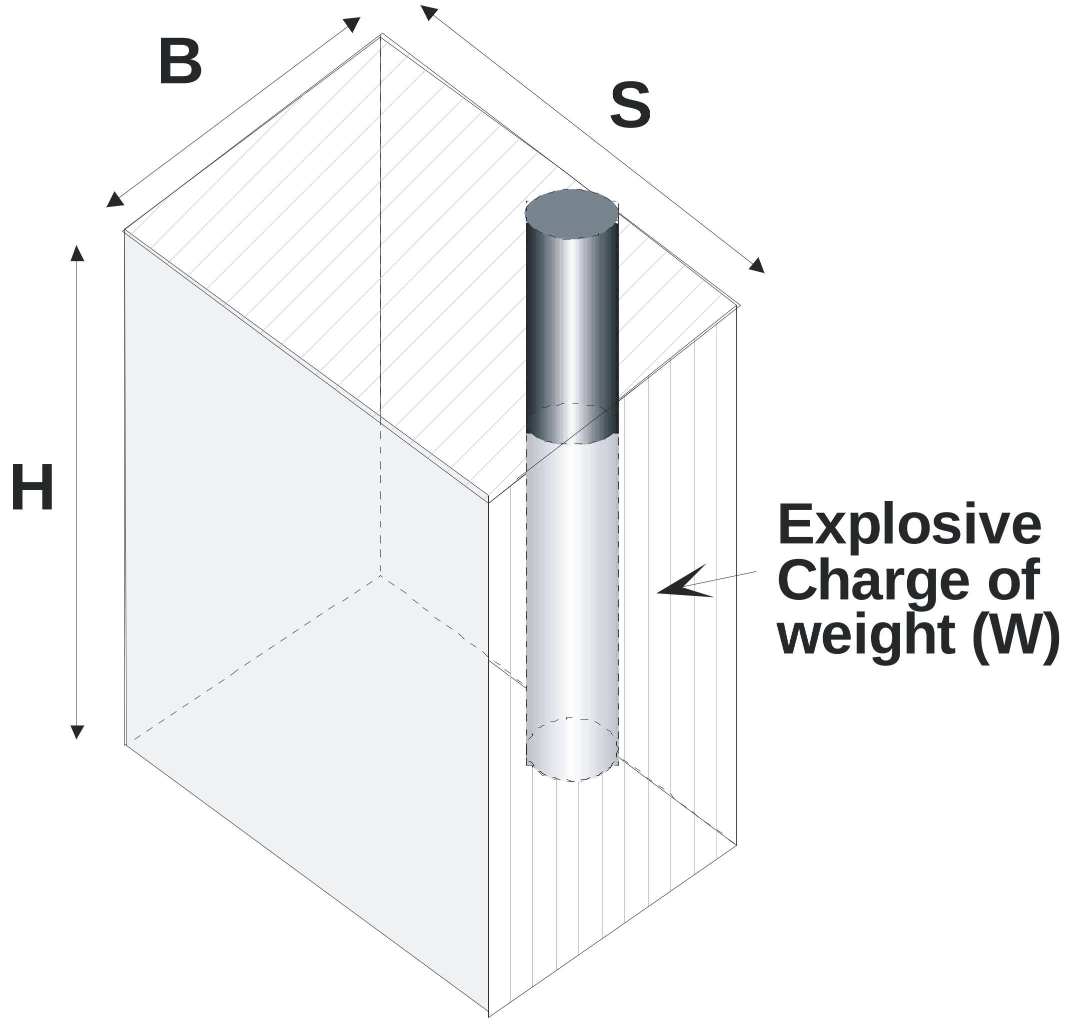
The quantities of rock excavated in construction projects are almost always measured by volume, so powder factors for this work are also related to unit volumes measured in either cubic meters (m^3) or cubic yards (yd^3). So construction powder factors are measured in:

$$PF = {}^{Ew}\!/_{Uv}$$

Where Ew = Explosive weight (lb) or (kg)

Uv = unit rock Volume (yd^3) or (m^3)

Simplified Powder Factor Illustration



Rock Volume per hole (V) = B x S x H

Powder factor = $\frac{V}{W}$

Similitude Relationships for Blast-Induced Vibration, Overpressure and Strain Prediction and Control

Gordon F. Revey – REVEY Associates, Inc. –April 2011

It is common industry practice to use empirical equations derived from geometric scaling theory to predict intensities of blast-induced vibration, over-pressure in air or water, and strain in materials of concern. The amount of energy produced by exploding charges confined in drilled holes is proportional to the weight (W) of the charge. This is a fair approximation because the unit weight strength of all commercial explosives is generally between 650 and 800 calories/g.

Distance (D) to the point of measurement defines the volume of ground, air or water into which energy from the charge is dispersed. Based on geometric scaling, these two variables can be combined to create a single variable called "scaled distance" that essentially defines the relative energy at any point of concern.

Square-Root Scaling**:** For linear explosive charges placed in holes drilled in rock, the energy of vibration-inducing strain waves radiating into the ground would generally disperse in a radial fashion; hence as the distance increases energy disperses inversely with the increasing distance radius. For this geometry, distance is divided by the square root of the charge size and the resulting dependent variable is the "scaled distance."

Cube-Root Scaling**:** When the height-to-width ratio of a charge is less than 6:1, the charge is considered a spherical charge and scaled distance is established by dividing distance by the cube-root of the charge weight. Cube-root charge scaling is also used for air-overpressure calculations and curves because the shape of pressure waves transmitted to air from blasted ground are generally spherical in shape.

To demonstrate the principle of dimensional similitude, consider the following comparison. If a 1-kg charge is fired in the ground, a specific intensity of vibration would occur in the ground at a distance of 10 m. Theoretically, it stands to reason that a larger charge of some size located 100 m from the same measurement point would also generate a similar level of vibration.

With square-root scaling, the scaled distance for the 1-kg charge at a distance of 10 m is 10-m-kg$^{-0.5}$ [10/1$^{-0.5}$]. If the size of charge in hole at a distance of 100 feet is increased to 100-kg, the scaled distance is also 10-kg-lb$^{-0.5}$ [100/100$^{-0.5}$]. Based on the principle of dimensional similitude, as shown in Figure 1, the estimated intensity of vibration expressed as the peak particle velocity or PPV in both cases would be approximately equal.

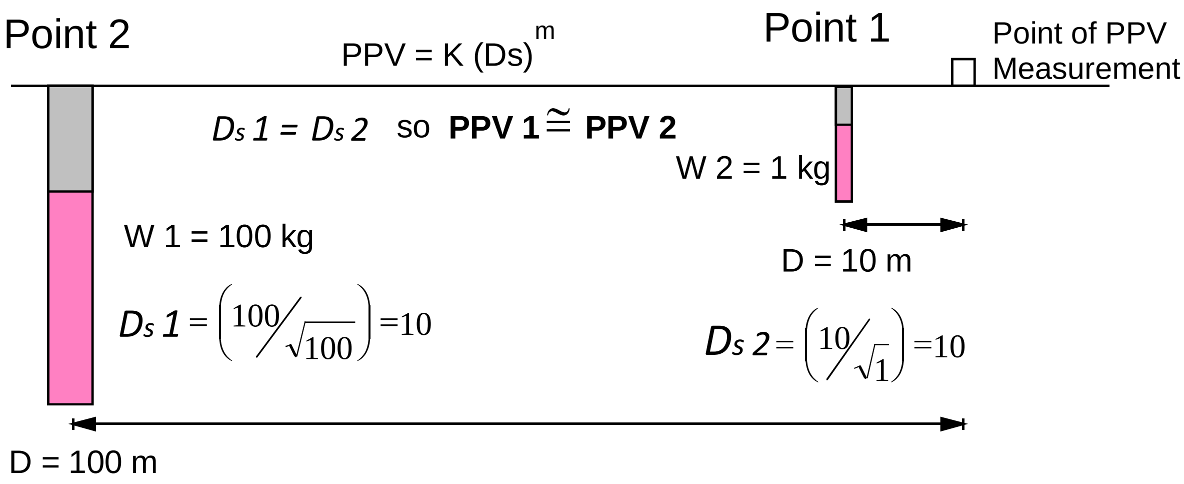


Figure 1 – Principle of Dimensional Similitude Scaling

Expressions of formulas demonstrating how square-root scaling is used for peak particle velocity (PPV) prediction follow.

$$PPV = K\left(D/\sqrt{W}\right)^{m} \qquad Where: D_s = \left(D/\sqrt{W}\right) \qquad So: PPV = K\ \left(D_s\right)^{m}$$

Where: PPV = Peak Particle Velocity - in/s (mm/s)
D = Distance – ft (m)
W = Maximum Charge-weight-per-delay – lb (kg)
K = Rock Energy Transfer Constant (K-Factor)
m = Decay Constant (always negative value)
D_s = Scaled Distance – ft/lb$^{1/2}$ (m/kg$^{1/2}$)

Log-Log Linearity: The empirical exponential-decay relationships used to predict intensity of ground vibration or air/water overpressure become linear in logarithmic form similar to the standard straight-line formula of the form Y = m X + B. In this case, Y = Log PPV, m is the slope of the curve with a negative value that generally defines the attenuation of energy with distance and Log K is the Y-Intercept (B).

When vibration data from specific sites is available, standard least-squares regression methods can be used to determine constants (K and m) for site-specific best-fit 50% and 95% upper envelope curves. For new projects where site specific data is not available, blasting engineers can estimate appropriate constants based on the strength of rock, elastic properties of the ground, water content, and confinement of blast charges.

As shown in Figure 2, vibration data and curves generally fall within the bounds defined by Oriard (1970). For curves with a presumed slope of -1.6, K values generally vary from 24 to 605 (171 to 4316 Metric) Curve slopes (m) for both imperial and metric (S.I.) units generally vary from -1.0 to -1.9.

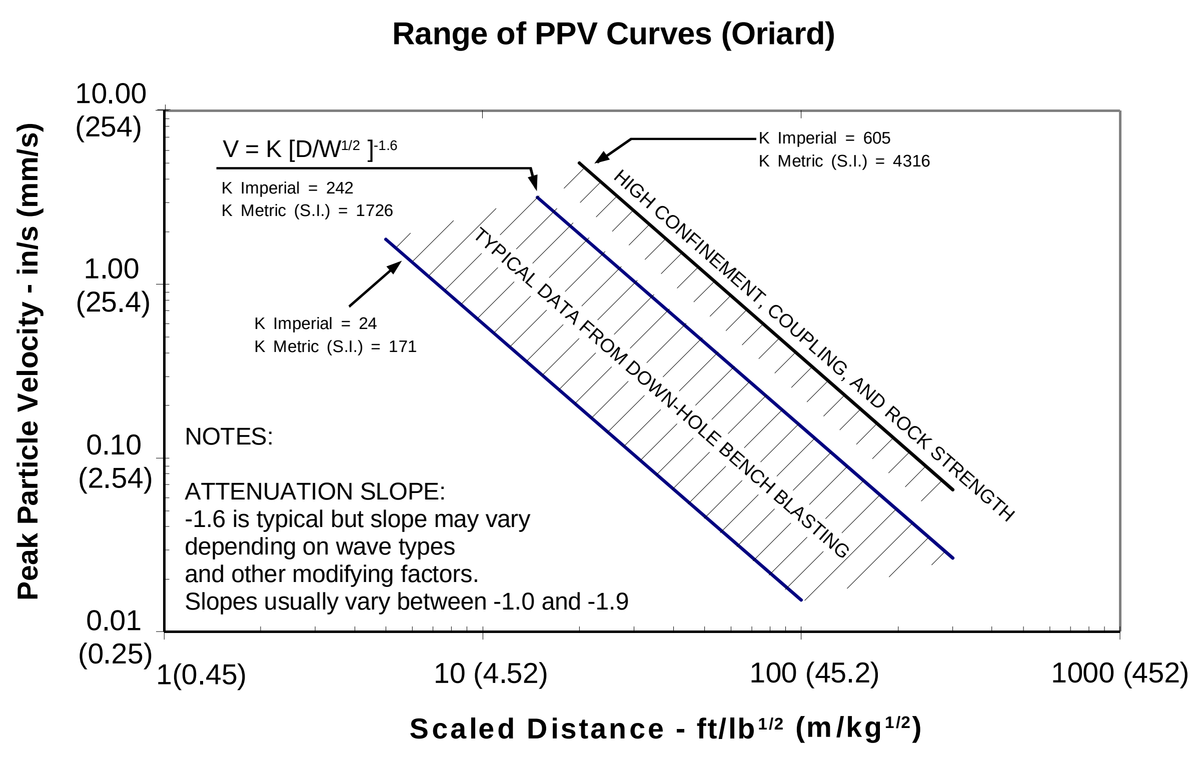


Figure 2 – Typical Boundaries of Vibration Data (Oriard, 1970)

When appropriate site constants are used, these empirical equations, based on the principle of dimensional similitude, generally compare quite well with equations derived by regression of actual site data. Sample regression curves for vibration, overpressure, strain and acceleration measurements made in various studies by REVEY Associates, Inc. are shown in Figures 3, 4, 5 and 6.

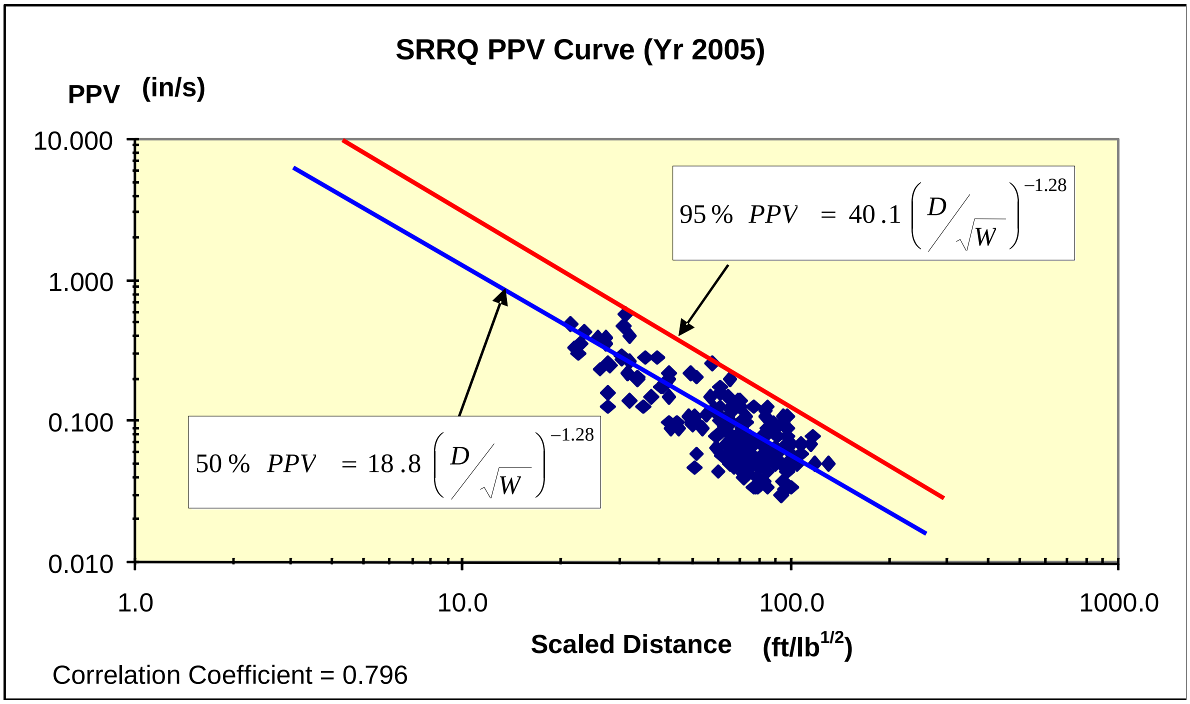


Figure 3 – Vibration attenuation curves for San Rafael Rock Quarry – Marin County, CA

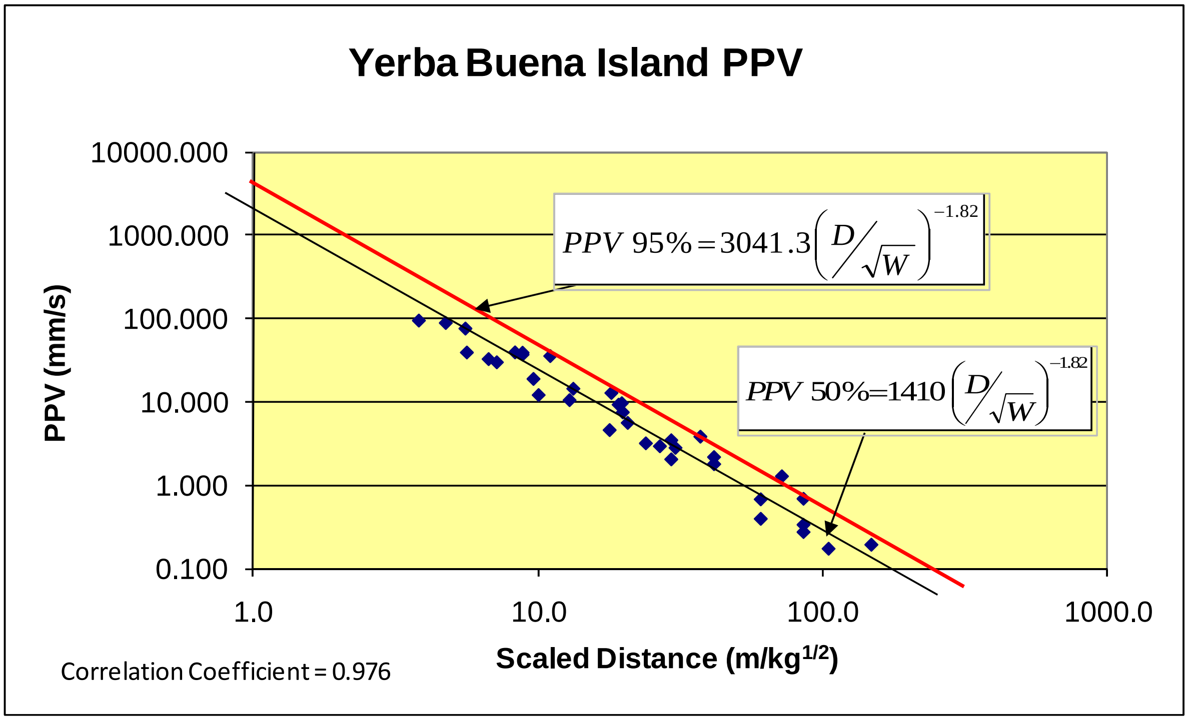


Figure 4 – Vibration attenuation curves for Yerba Buena Island – San Fransisco, CA

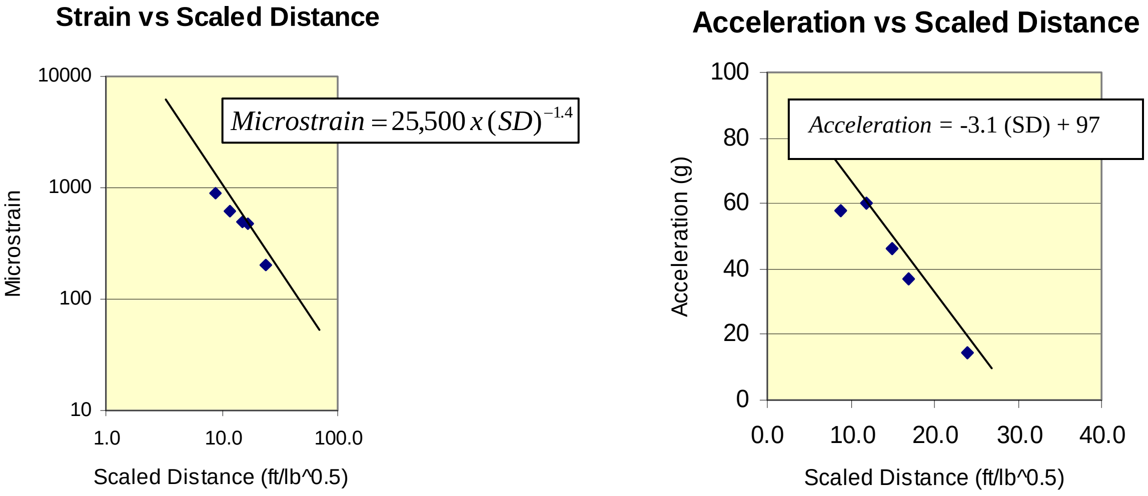


Figure 5 – Data and Curves for Blast-Induced Strain & Acceleration Measured in Concrete

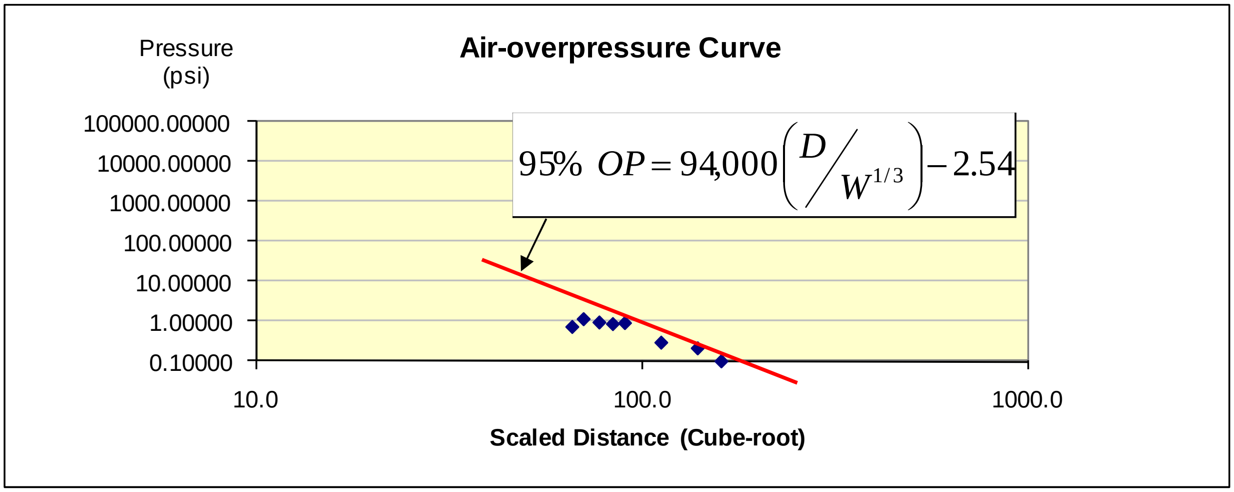


Figure 6 – Air-Overpressure Curve based on Cube-Root Scaling

Using Scaled Distance Relationships to Establish Safe Charge Weights

By setting PPV, overpressure or strain equal to a mandated limit, prediction equations can be rearranged to calculate a minimum Scaled Distance (D_s) value that blasters can use to calculate maximum charge weight-per-delay. The form of the rearranged formula for particle velocity follows. Similar relationships are used for overpressure, strain, acceleration, etc.

$$Ds = \left(PPV / K\right)^{1/m}$$

For example, if the desired PPV-limit for buried pipes is 5.00 in/s, with cautious constants with K = 240 and m = -1.6, the limiting Scaled Distance (D_s) is 11.2 ft-lb$^{-0.5}$ [(5.00 / 240) $^{(1 / -1.6)}$].

Once minimum scaled distance values are established in project specifications or blasting plans, field blasters can use very simple equations to determine maximum charge-weights-per-delay – or the maximum weight of explosive firing within any 8-millisecond time frame. When electronic-delay detonators are used, the delay windows can be reduced to 5 or so milliseconds without incurring cumulative effects of so separated charges. The simple relationship between scaled distance and maximum-charge-weight-per-delay (W) is:

$$W = \left(D / D_s \right)^2$$

Where: D = distance – ft (m)
D_s=Scaled Distance - ft-lb$^{-0.5}$ (m-kg$^{-0.5}$)
W = Maximum-charge-weight-per-delay – lb (kg).

All licensed and capable blasters are trained to understand and apply scaled distance equations. For example, if a blast occurs 50 feet from the buried pipe where a minimum scaled distance of 11.2 would be used to keep the intensity of vibration below 5.0 in/s, the maximum charge-per-delay would 19.7 pounds [(50 / 11.2)^2]. If the distance increases to 300 feet, the allowable charge-per-delay increases dramatically to 712 pounds [(300 / 11.2)^2].

Establishing minimum scaled distance controls, in addition to firm not-to-exceed PPV limits, provides additional protection by taking some of the guesswork out of learning what charge sizes are needed to conform to certain vibration and overpressure limits.

References:

Oriard, L.L., (1970). “Blasting Operations in the Urban Environment,” Association of Engineering Geologists Annual Meeting, Washington, DC, October 1970, published in Bulletin of AEG, Vol. IX. No. 1, October, 1972.

Practical methods to control explosives losses and reduce ammonia and nitrate levels in mine water

G.F. REVEY

G.F. Revey, member SME, is president, Geotek & Associates, Inc., Highlands Ranch, CO. SME preprint 95-26, SME Annual Meeting, March 6-9, 1995, Denver, CO. Original manuscript February 1995. Revised manuscript October 1995. Discussion of this peer-reviewed and approved paper is invited and must be submitted, in duplicate, prior to Oct. 31, 1996.

Abstract

Most commercial explosives contain from 70% to 94% (by weight) ammonium nitrate. When some of the explosives end up in shot rock and ore, through either spillage or incomplete detonation, ammonia and nitrates can leach into the ground water. In recent years, state and federal regulators have applied more stringent water-quality standards, particularly at new mines and development projects.

When mining conditions permit, bulk ANFO, a mixture of ammonium nitrate and fuel oil, is the explosive of choice. ANFO is less costly than other explosives but it dissolves readily in water. Several case histories in the United States and Canada show a clear connection between uncontrolled losses of bulk explosives and high nitrate levels in mine effluents.

Mining companies have tried several approaches to reduce ammonia and nitrate levels in groundwater. These approaches range from controlling explosive losses to treating the mine effluents. In this paper, controlling explosive losses is addressed. For both packaged and bulk explosives, guidelines to limit losses during storage, handling and use are described in detail.

Ammonia and nitrate toxicity

Relatively small concentrations of ammonia in water are very detrimental to fish, particularly most trout species. The toxicity of ammonia varies with pH and temperature. Researchers have found that, at lower temperature and pH, the toxicity of free ammonia increases (Wiber et al., 1991). In aqueous solutions, ammonia exists in two forms: free ammonia, which carries no ionic charge (NH_3), and ammonium, which carries a positive charge (NH_4^+). The free ammonia is the more toxic of the two. The US Environmental Protection Agency's (EPA) ambient water quality criterion is 0.02 mg/L free ammonia. For United States mines, NPDES permits commonly include a limit of 10 mg/L total ammonia as N in end-of-pipe effluents. The EPA drinking-water criterion for nitrate as nitrogen (NO_3^--N) is 10 mg/L. In warm-blooded animals, nitrate can be reduced to nitrites in the gastrointestinal tract. The nitrite reaches the bloodstream where it reacts directly with hemoglobin to produce methaemoglobin that impairs oxygen transport.

Ammonia and nitrate sources

Many mines have learned that there is a direct relationship between the ammonia and nitrate levels in water and the amount of undetonated explosives in the rock through which the water flows. Most commercial blasting agents contain from 70% to 94% ammonium nitrate. ANFO, the most commonly used blasting agent, is usually a mixture of 6% #2 diesel fuel oil (DFO) and 94% ammonium nitrate. ANFO readily dissolves in water, releasing both ammonia and nitrate. Emulsion and watergel-based explosives also contain a large amount of ammonium nitrate and other oxidizing salts that can leach nitrates to ground water. The rate at which nitrates leach from different explosives varies dramatically, based on the explosive's composition. In tests conducted at the ICI Explosives Technical Center in McMasterville, Quebec, Canada, nitrate leaching rates were established for the following:

- standard ANFO,
- WR "water resistant" ANFO (with additives to inhibit the ingress of water),
- detonator-sensitive watergel, and
- detonator-sensitive emulsion.

Table 1 shows the cumulative nitrate leached from these explosives at different exposure hours (Watson, 1991).

As expected, the emulsion did not release nitrates as readily as the ANFO or watergel explosive. The leaching rate for emulsion explosives is much lower, because the ammonium nitrate is contained in an aqueous phase that is surrounded by an oil (or oil and wax) fuel phase. Hence, when water contacts undetonated emulsions, the ammonium nitrate is protected by the relatively impervious oil and wax matrix. Despite their very slow leaching rates, emulsions (when given enough water exposure time)

TABLE 1

Percentage of nitrates leached from explosive*

Time, hr	ANFO	WR ANFO	WaterGel	Emulsion
0.1	~25	—	—	—
1	> 50	~25	—	—
6	—	—	24.6	0.6
144	—	—	> 75	1.2

* When 25% of the nitrates are dissolved, the explosive is probably no longer detonable.

FIGURE 1

Projectile impact test

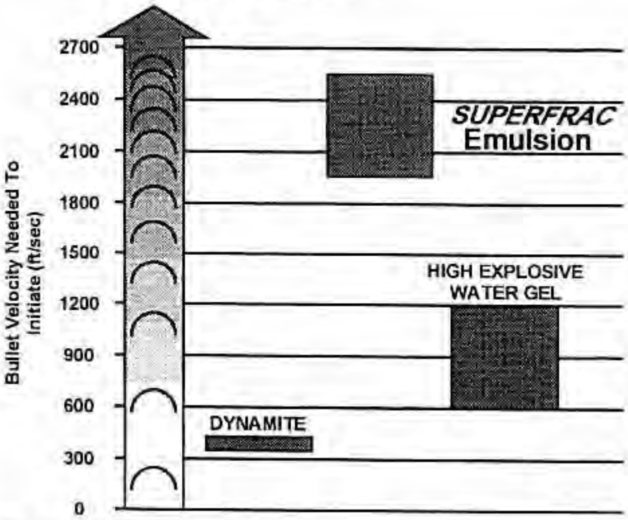
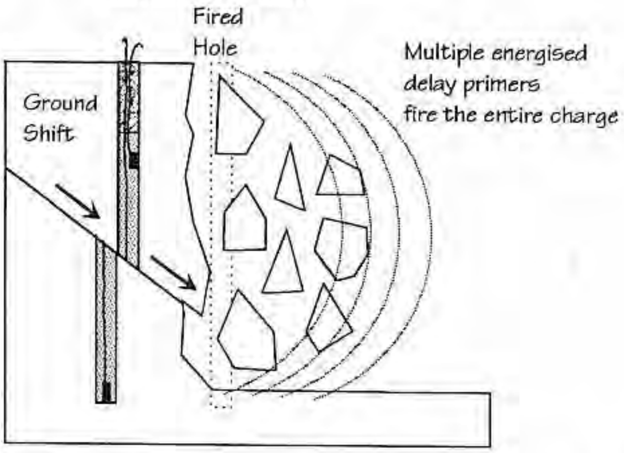


FIGURE 2

Multiple priming to prevent rock movement cutoffs.



can produce significant levels of nitrates and ammonia. By comparison, spilled ANFO will quickly dissolve in water and release all its ammonia and nitrates. If continuously spilled, the daily level of nitrates and ammonia released by any type of explosive that is exposed to water will eventually become significant. The ammonium nitrate leaching rate for packaged explosives will vary based on the integrity of the package. However, this is usually a moot point, because packages of undetonated explosives are almost always ruptured by the violent rock movement within the blast. Despite being ruptured, the packaged explosive can often be recovered from shot rock. Nitroglycerin- (NG-) based dynamites will also leach ammonia and nitrates at varying rates based on their composition. In addition, NG-sensitized products are much more sensitive to shock impact; for this reason, as well as environmental concerns, the occurrence of unfired dynamite in shot rock should be prevented (Fig. 1).

In underground metal mines, noxious levels of ammonia gas often occur when undetonated explosives mix with alkaline water draining from cemented fill or grouting operations (Joyce, 1992). This parallel ammonia problem is another reason to control explosive spills.

The conclusion from this analysis is that losses of all types of explosives must be controlled, regardless of their composition or packaging.

Managing explosives losses

There are several ways that undetonated explosives end up on the ground or in shot rock. First, sloppy handling, storage and loading practices may cause a significant amount of explosive spillage, particularly when bulk explosives are used. Poor drilling and loading practices can also cause significant amounts of explosives to remain undetonated. Charges are often disrupted or torn away by premature rock movement caused by earlier detonations. Drill patterns, stemming or collar length, explosive selection, priming methods and delay timing are the elements of blast design that can be adjusted to control charge cutoffs or failures.

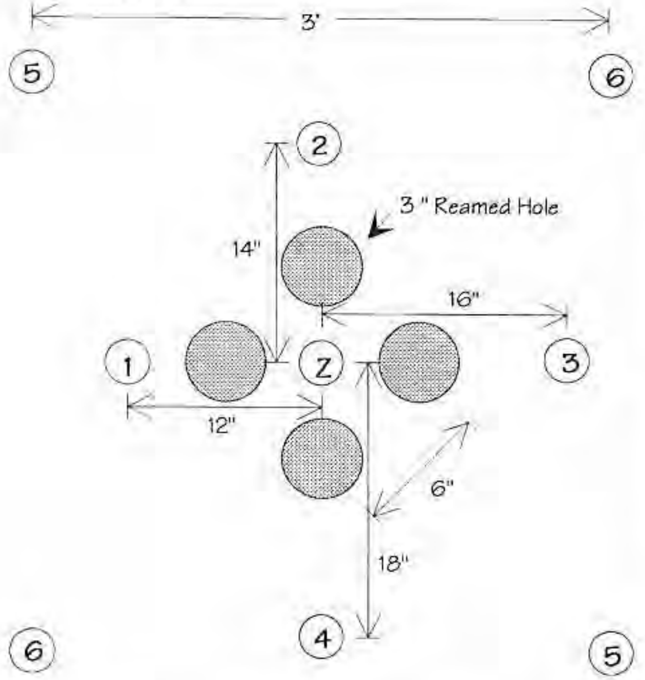
In a paper presented at the 1991 Northwest Mining Association convention in Spokane, WA, the authors discussed water-monitoring case histories from three separate underground mines in Canada (Wiber et al., 1991). In all three cases, the levels of ammonia in mine water were lowered by at least 50% after rigorous explosive management programs were started.

Storage and handling controls. In both surface and underground mining, ANFO and bulk-emulsion blasting agents are often spilled during storage, transfer or loading. Bulk ANFO commonly spills out of poorly designed or damaged bins, rail cars and transfer augers. Bulk-emulsion spills are often seen at storage-tank outlets and at pump-transfer areas. Maintenance employees are an important part of a complete explosives-management program. They should understand that all bins, tanks, storage trailers and loading equipment should be regularly maintained to prevent explosives spills. Employees who understand the importance of preventing explosive spills can greatly reduce their occurrence. However, no level of training will completely prevent all spills; so it is important to develop spill containment and clean-up procedures. To contain spills, some surface mines have placed their bulk-explosive bins in concrete containment tanks, or they constructed rock berms around tanks and bins. Explosive manufacturers can usually provide spill clean-up recommendations for their products, and, in many areas, they can provide special mobile clean-up crew and equipment services.

Blast-design considerations. For safety, environmental and economic reasons, blast designs should include measures that ensure complete detonation of all explosives. For this analysis, any charge or portion of a charge that fails for any reason is considered a misfire. Some common causes of misfires, along with design practices

FIGURE 3

Shielded blasthole burn cut for 45 to 50 mm (1.75 to 2 in.) jumbo rounds.



that will prevent them, are given below:

Cutoffs. We cannot control ground conditions, but we can control drill patterns, explosive loads and initiation methods. In ground having weak seams or joints, the gasses and the shock from early firing charges can cause premature movement of the rock containing adjacent, unfired holes. When the rock moves, it separates or cuts off the explosive columns within it. The portions of the columns that do not contain energized primers will misfire and contribute ammonia and nitrate to ground water. Many of these misfires can be prevented by using multiple in-hole delay primers (Fig. 2).

Some failures occur because there is too much delay time between the adjacent holes or rows of holes. In these situations, reducing the delay time between holes can reduce cutoffs. Cutoffs and explosive losses often occur when detonating cord down lines, and surface delays are used in bench blasting. When detonating cord is used without a delay detonator in the hole, the ground swell that occurs when the first row of holes fires, can tear cord and delay connections before they fire, hence, causing multiple hole failures. This type of cutoff can be prevented by using fully activated sequential timing (FAST) systems that use relatively long in-hole delays in combination with short surface delays. The goal with these systems is to have all of the in-hole initiators sequentially energized before the first charges fire and rock starts moving. In very large shots that cannot be fully energized, one should try to have at least two rows energized behind the row that is firing. FAST sequential timing can be achieved with either nonelectric- or electric-initiation systems.

Precompression failures. Several blasting problems can occur when hole-to-hole shock pressures are too high. High blast-induced pressure in rock can cause sympathetic detonation (propagation) of dynamite charges and precompression failure in emulsion and watergel explosives. Many blasting incidents, often with severe damage to nearby structures, have been caused by propagating dynamite. In critical blasting areas, the propagation hazard is virtually eliminated by substituting less sensitive explosives for dynamite. However, under certain conditions, packaged emulsion and watergel explosives can fail when rock or gas pressure from an adjacent charge squeezes them to a density above their critical limit. This precompression or "dead-pressing" phenomenon is caused by several conditions or combinations of conditions. When the ground is very seamy and wet, the magnitude of hole-to-hole shock is greatly increased. Shock also increases when the holes are very close together, which is always the case in underground tunnel and surface ditch blasting where the application demands tightly spaced holes. If precompression failures occur, one should try spacing the blastholes farther apart or switch to an explosive that can withstand higher pressures. In tunnel rounds, the holes in the burn cut are usually spaced very closely together. The hole-to-hole pressure transmitted to the charges in these holes can be reduced by placing unloaded relief holes between the loaded holes (Fig. 3).

Poor explosives choice. The type of explosive used can have a dramatic effect on overall losses. For instance, if bulk explosives are used instead of packaged explosives, spillage losses will be relatively high. If bulk ANFO is used in wet holes, losses caused by complete failures or partial detonation will be high. At one underground metal mine in the northwest United States, their total daily limit of nitrates in ground water is 45 kg (100 lb.) To meet this limit, they can not tolerate any spillage, so they use only packaged explosives. Moreover, they use Magnafrac 3000, a special emulsion product with a distinctive orange color that can be seen and removed from shot rock.

When conditions that cause very high hole-to-hole shock pressures exist, only explosives that can resist precompression should be used.

Loading controls. Without specific controls, mines using bulk ANFO typically lose 2% to 5% to spillage and blow back during pneumatic loading underground. Surface auger-loading trucks with poorly designed, or aimed, discharge hoses spill ANFO prills onto the ground around hole collars during loading. Wind can also add to losses by carrying some prill away from the hole if the discharge hose is too high in the air. Blasters who are conscientious and aware can prevent most spills by simply adjusting their loading practices. Moreover, when spills do occur, they must know how to clean them up; and they must understand the importance of doing it.

For some loading applications, explosive makers are developing specialized equipment and products designed to reduce explosive losses. For instance, a pneumatic ANFO-metering device that cuts ANFO losses by 10% has been developed by the bulk-technology group of ICI Explosives Inc. This "ANFO Miser" reduces blow-loading losses by metering a preset amount of explosives into a blasthole, thus, preventing overloading. ICI Explosives Inc. also developed Amex Ultra, a specially formulated ammonium nitrate and fuel prill that has virtually no blow-back loss when pneumatically loaded in underground blasting operations.

In many underground blasting applications, overloading is the greatest cause of explosive losses. When

FIGURE 4

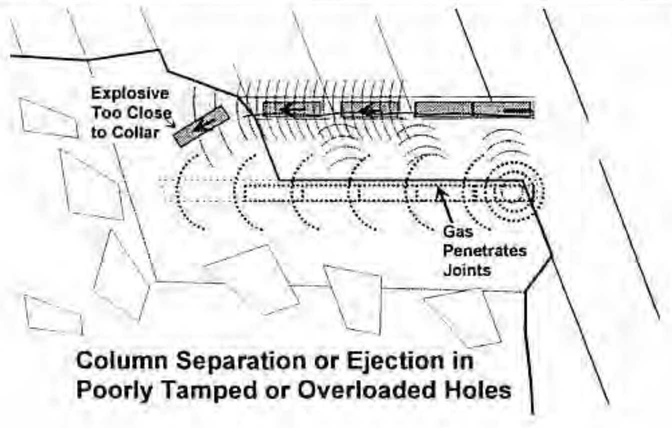
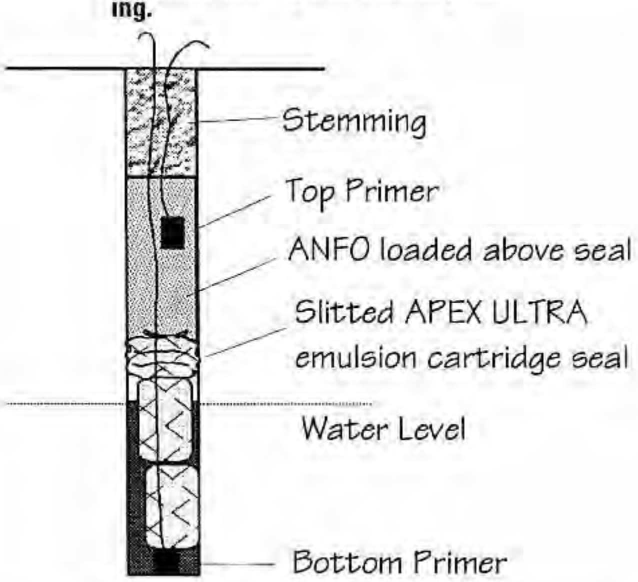


FIGURE 5

Borehole sealing and double priming.



long-period delay detonators are used to delay tunnel and other development rounds, the charges in the later firing holes are subjected to tremendous shock and gas pressure generated by the earlier firing charges. This shock and pressure often tear away the rock around the collars of adjacent and yet unfired holes. Any explosive, whether in stick or bulk form, that is in this collar region is cut off and ends up undetonated in the shot rock. To control these losses, minimum open collar lengths should be established for all underground blast loads, based on geological conditions and application. Cartridge ejection from hole collars will also cause explosive losses. Ejection losses can be reduced by firmly tamping the cartridges near the hole collar. However, never tamp the primer stick — this practice is dangerous and is prohibited by MSHA. When charge tamping will cause overloading, the explosive column can be secured by some type of hole plug. To accurately implement good blast designs, operations must have proper loading equipment and trained employees. Loading equipment should be well maintained, and, in some cases, mines should consider using computerized bulk-loading equipment that meters preset weights of explosives into blastholes (Fig. 4).

Sometimes during loading, packaged explosive columns are separated when rock chunks fall into the hole or when a cartridge becomes stuck. When this occurs, the separated portion should be separately primed with the same delay detonator used in the initial primer. Use of the same delay will prevent one part of the separated charge from disrupting the other, and the desired firing sequence will be maintained.

Loading bulk ANFO into wet holes or letting ANFO "sleep" too long in wet or damp holes are also common causes of explosive loss. When water comes into contact with ANFO, it either dissolves it or wicks into it and desensitizes it. In either case, the ANFO charge partially or completely fails to detonate. In underground development rounds, static drill water should be blown out of holes with compressed air before pneumatically loading ANFO. In top-loaded vertical holes, water-resistant cartridged or bulk explosives should be substituted for ANFO.

In wet holes, packaged explosives are often not loaded until out of water and the load is finished with ANFO. If the hole is not sealed, the ANFO will sift past the packaged ANFO and dissolve in the water. The water will cause further ANFO loss when it wicks up the sifting ANFO into the main column. This problem is a common cause of misfires in bench-blasting applications. Holes should be sealed with a fully coupled and waterproof explosive before loading ANFO. A good seal can be made by dropping a cut stick of an emulsion explosive, such as Apex Ultra, into the hole before pour loading ANFO (Fig. 5).

Conclusion

At all mines, significant reductions in the amount of ammonia and nitrate in mine water can be achieved by developing an aggressive and ongoing explosive-management program. At three different mines in Canada, the implementation of rigorous explosive-management programs reduced ammonia levels by at least 50% in all cases.

As responsible stewards of our environment, mining companies and explosive suppliers should work together to establish products, loading equipment and training programs aimed at lowering toxins in mine effluents. Explosive manufacturers, aware of these environmental concerns, are developing new explosive products and loading equipment specifically designed to reduce explosive losses. Excellent slide and video training programs for explosive handlers are also available. Everyone should take action and work with their explosives supplier to prevent ammonia and nitrate compliance problems. Mines that wait to act until the ammonia and nitrate limits have been exceeded will pay huge remedial-control costs. ■

References

Joyce, D.K., 1992, "Ammonia gas generation from ammonium nitrate in alkaline conditions," ICI Explosives Canada Report.

Wiber, M., et al, 1991, "Environmental aspects of explosives' use," Northwest Mining Association Short Course Report, Spokane, WA, December.

Watson, C.G., 1991, "Ammonium nitrate leaching from explosives," Internal ICI Explosives Report, Explosives Technical Center, McMasterville, Quebec, Canada, February .

Kline Report

AECOM
2101 Webster Street
Suite 1000
Oakland, CA 94612
www.aecom.com

510.419.6000 tel
510.419.5355 fax

May 11, 2011 (Revised July 15, 2011)
Project No. 60196699.0002

Mr. David Lippman, PE
Director of Facilities and Operations
Las Virgenes Municipal Water District
4232 Las Virgenes Road
Calabasas, California 91302

Dear Mr. Lippman:

Subject: **Geotechnical Evaluation of Blasting Near Las Virgenes Dam**
Proposed Sites A and C - 5 MG Water Tank at Las Virgenes Reservoir

Per our February 4, 2011 Scope of Work, AECOM Technical Services, Inc. (AECOM) is providing this letter report discussing the possible effects of blasting proposed for excavation at Tank Sites A and C, specifically regarding the nearby Las Virgenes Dam and its foundation. Input is also provided regarding jurisdictional control over the Las Virgenes Dam by the California State Division of Safety of Dams (DSOD) associated with the proposed blasting. This report is directed toward assessment of the acceptability of the proposed tank construction blasting relative to the nearby dam, assisting the Las Virgenes Municipal Water District (LVMWD) in assessing risks and in their dealings with DSOD and other concerned parties.

BACKGROUND

LVMWD is planning to construct a 5 million gallon capacity water tank at its Las Virgenes Dam and Reservoir site. Two sites are currently under consideration. Site A is adjacent to the left abutment of the west saddle dam. Site C is located southeast of the east abutment of the main dam, but at a much greater distance. The preparation of Site A would require approximately 16,500 cubic yards of excavation, while Site C could only require about 4,800 cubic yards of excavation. Fugro Consultants, Inc. (Fugro) has performed a geotechnical and geophysical evaluation of Site A along with presentation of rock excavation methods for preparation of the site for tank construction. Considering the relatively massive, hard volcanic rock at the tank excavation site, Fugro concluded that blasting would be the preferred method for site preparation excavation. Blasting might also be preferable for the preparation of Site C, although that site has not been studied in as much detail, because it is much more remote from the dam and any residences.

On March 16, 2011, we attended a site visit and meeting to review the proposed project, observe field conditions at the proposed tank sites, and discuss blasting methods, criteria, controls, and concerns for the project. In attendance were LVMWD operations and engineering staff, Fugro geologist (Tom Blake), AECOM project management (Dan Ellison), AECOM dams consultant (Stan Kline), and blasting specialist consultant, (Gordon Revey of REVEY Associates, Inc.). In addition to observing the proposed tank site conditions, an understanding of the surrounding environment in the vicinity of the proposed blasting location was obtained, including the dam and its associated appurtenant facilities, and the nearby downstream residential development.

In support of the geotechnical and dams oriented blasting evaluation, certain background material, documents, and other supporting materials were supplied and reviewed, as follows:

- Westlake Reservoir Site and Laboratory Investigation by W. A. Wahler & Associates, dated September 1969.
- Evaluation of Alternatives for Construction of Westlake Dam and Reservoir by Boyle Engineering, dated November 1970.
- As Constructed Plans for Westlake Reservoir Dam and Appurtenances, dated 1973.
- Westlake Reservoir Dam - Seismic Safety Evaluation by Woodward-Clyde Consultants, dated February 1993.
- 2010 Las Virgenes Dam Settlement Report by LVMWD, dated March 2010.
- Preliminary Geotechnical and Geophysical Evaluations, and Discussion of Potential Rock Excavation Methods, Proposed Las Virgenes Water Storage Tank Site A by Fugro West, Inc., dated July 19, 2010.

In addition, a number of readily available references containing blasting industry standards and criteria were reviewed relative to establishing the standard of practice applicable to the proposed tank project, with blasting adjacent to the earthfill dam. This included of particular note, a U. S. Bureau of Reclamation technical report entitled Review of Present Practices Used in Predicting the Effects of Blasting on Pore Pressures, dated November 1985.

There is also history or track record with blasting, similar to that proposed for the tank construction, carried out at the dam and reservoir site, associated with construction of the filter plant on the bedrock abutment between the saddle dam and main dam. Only a few reports and documents relative to this previous blasting experience were available for review, but the Resident Engineer, AECOM’s Glen Hille, was interviewed. This earlier blasting project was successful and completed without incident, and was performed with DSOD oversight. Appendix A contains the permit, specifications and excavation plan used during the 1988 project, as well as photos showing the blasting work.

In addition to the background material review, the current overall blasting evaluation report and associated proposed blasting technical specifications (submitted just prior to this geotechnical and dams oriented report, by REVEY Associates, Inc.) provides blasting methods, criteria, and controls relevant to this report’s more specific evaluation of blasting effects to the dam and its foundation. Review of this comprehensive project material by the blasting consultant specialist is part of the scope supporting this evaluation report.

PERTINENT DAM CHARACTERISTICS

Characteristics of the Las Virgenes Dam embankment that are pertinent to this potential blasting effects evaluation are as follows:

- Dam construction in 1971 / 1972.
- Seismic safety evaluation conducted in 1993.
- Zoned earth and rockfill embankments.
- Rests on a hard volcanic bedrock foundation.

- Maximum embankment heights of 160 feet for the main dam and 55 feet for the saddle dam.
- Central impervious core zone of primarily lean clay material.
- Outer shell zones of primarily clayey gravel and clayey sand materials.
- Downstream toe rockfill zone.
- Filter zones, surrounding the central core, of pervious sand and gravel materials.
- Drain zones, downstream of the central core and filter, and beneath the downstream shell, of pervious, clean gravels.
- Grout curtain into the bedrock foundation beneath the central core.
- No internal piezometric monitoring devices.
- Downstream embankment / foundation seepage weekly monitoring, automated in 2009.
- Embankment crest and downstream slope horizontal and vertical displacement monitoring annual surveying.

(Attached to this report for reference are drawings showing plan and cross-sectional views of the main dam and the saddle dam, including the zones described above. The approximate locations of Site A and Site C have been added to the first drawing.)

BLASTING EFFECT CONCERNS

The typical types of potential adverse effects of blasting, specifically to an earthen dam and foundation, established for consideration are as follows:

- Liquefaction of saturated materials subject to this phenomenon upon vibration creating excess pore pressures.
- Increase of embankment or foundation pore pressures, with negative impact on stability if excessive.
- Settlement of susceptible materials upon vibration.
- Excessive peak particle velocity (PPV), or vibration intensity, generated by the blasting, correlating to resultant structural damage.

BLASTING EFFECT ASSESSMENT

Relative to the above potential adverse effects of blasting to an earthen embankment, the following discussion points support the general assessment that proposed blasting at either location, Site A or Site C, for the water tank foundation will not have detrimental effects on the dam or its foundation from an operations or safety perspective, considering the actual site conditions and how the dam was constructed, and provided that methods, criteria, and controls recommended by the blasting consultant specialist are followed. It is expected that DSOD would reach the same conclusion when presented with the proposed blasting plans.

- The seismic safety evaluation conducted for Las Virgenes Dam in 1993, as well as documented earlier safety evaluations and the original project design documents, conclude and establish that the various engineered fill materials comprising the dam embankment have low liquefaction potential. This aspect of the dam design and construction, in addition to the dam being founded on bedrock, essentially negate the primary concern of blasting near earthfill dams related to liquefaction potential.
- The 1993 seismic safety evaluation concludes that the dam embankment materials are generally dilative and strong, and are not likely to have significant loss of strength due to

increased pore pressure during the evaluated maximum credible earthquake shaking event. Considering the much less severe vibration effects of blasting than major earthquake shaking, a concern of reduced embankment stability associated with blasting is negligible.

- Given the dam embankment engineered fill comprised of compacted soil and rock materials placed under strict relative compaction standards and resting on a bedrock foundation, the susceptibility of the dam to blasting vibration induced settlement is very low.
- The overall blasting evaluation report and associated proposed technical specifications developed by the blasting consultant specialist, REVEY Associates, Inc., establishes a maximum PPV limit of 2 inches per second, generated by the blasting program as designed, at the closest location of the dam. This will protect the various compacted embankment fill zones from blast-induced motion and associated structural damage. Typically, 4 inches per second is an acceptable PPV limit for dams not having materials in the embankment or foundation sensitive to vibration. This is a U. S. Bureau of Reclamation industry standard and considered a standard of practice as applied here. The proposed PPV limit of 2 inches per second thus provides an even larger margin of safety. It is generally understood that the amount of damage from blasting correlates best to the PPV. Peak ground acceleration, on the other hand, is more appropriate when evaluating damage for earthquakes.

RECOMMENDATIONS

Proposed blasting for the water tank construction adjacent to the Las Virgenes Dam, carried out, controlled, and monitored as recommended in the REVEY Associates, Inc. blasting consultant specialist evaluation report and technical specifications, will not have detrimental effects on the dam or its foundation from an operations or safety perspective. Some prudent associated recommendations are developed for consideration, as follows:

- Involve DSOD as early as possible in the review and evaluation of the proposed tank construction plans with associated blasting, as it pertains to concerns relative to the adjacent jurisdictional dam. This will be beneficial to expediting the project approvals under their control and minimizing unexpected requirements.
- Although the Las Virgenes Dam does not have piezometer instrumentation for monitoring pore pressures, which would be desirable associated with blasting events, instrumentation has been installed that provides continuous seepage measurments. Data from these instruments should be monitored closely during the blasting work, as an indirect indicator of pore pressure changes from blasting.
- As part of the overall project requirements and controls, institute the procedures and requirements for monitoring blast-induced vibration to be able to confirm that the 2 inches per second PPV value is not exceeded at the dam.
- Adopt the blasting consultant specialist recommendations and associated proposed blasting methods, criteria, and controls, including the customized project specific training for the various project participants for increased project success, efficiency, and cost-effectiveness.

We hope this report meets your present needs relative to consideration of proposed blasting for the tank project at the Las Virgenes Dam, specifically associated with any effects to the dam and foundation. Please contact us if there are any questions or further discussion desired.

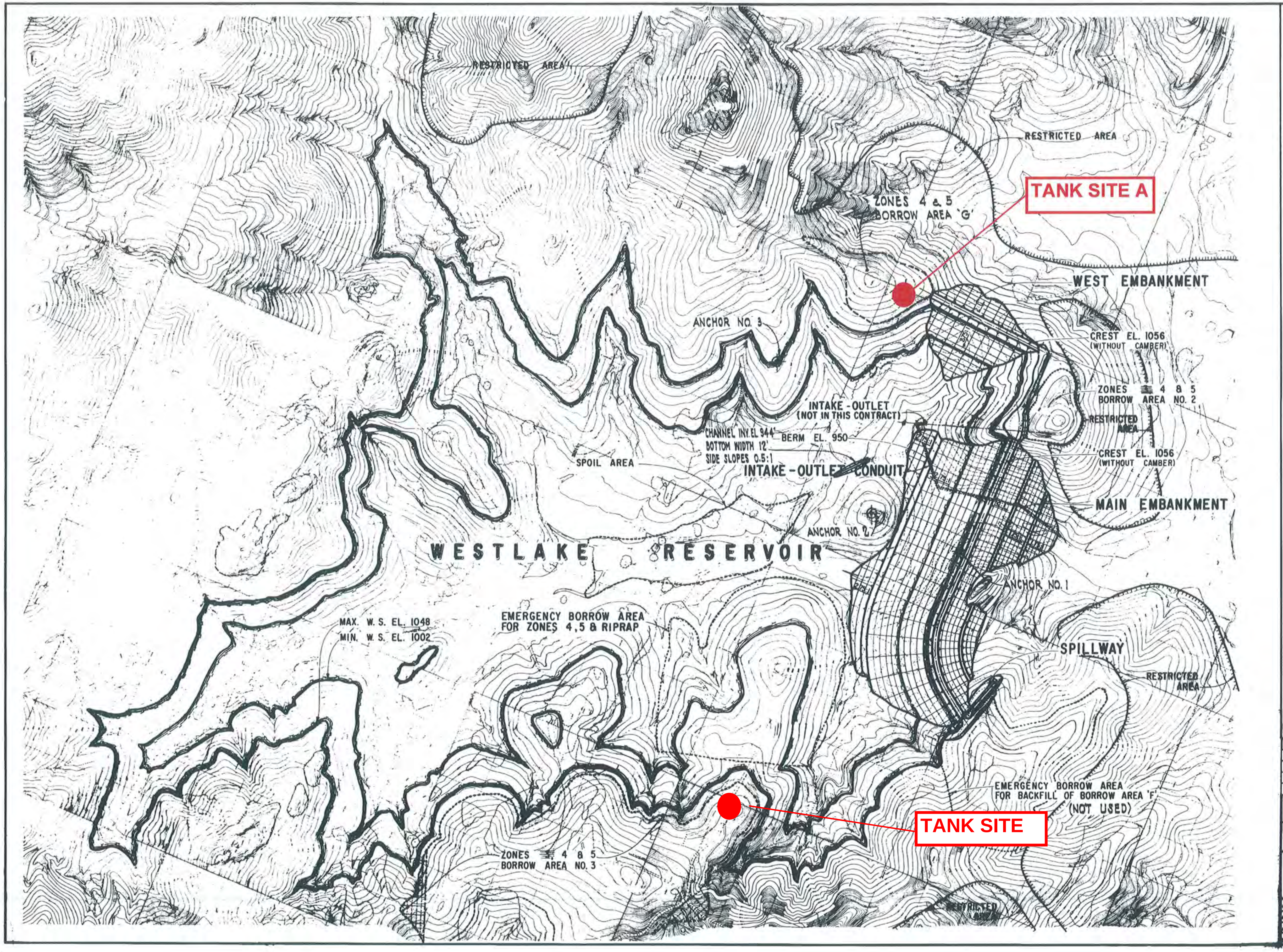
AECOM Technical Services, Inc.

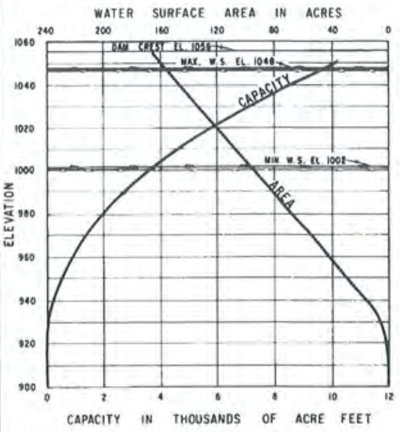
Stanley H. Kline Dan Ellison

Stanley H. Kline
Senior Geotechnical Engineer
RCE No. 30575, California
GE No. 477, California

Dan Ellison, PE
Project Manager

Enclosures: LVMWD Record Drawings: 05251, 05266, 05268, 05282 & 05283



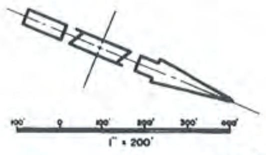


RESERVOIR AREA - CAPACITY CURVES

NOTES

1. Contractor shall not operate equipment of any kind within the designated restricted areas, or otherwise disturb the natural features, including trees, brush, ground cover and rock formations.

AS CONSTRUCTED
DATE 4/5/73 DFT H.H.R. CKD D.F.M.



05251

NO.	DATE	REVISIONS	BY	CHK	JOB ENG.	PROJ. ENG.	MGR.
△	11/1/70	ISSUED FOR CONSTRUCTION	T.S.M.	W.S.T.	D.F.M.	A.H.	L.C.

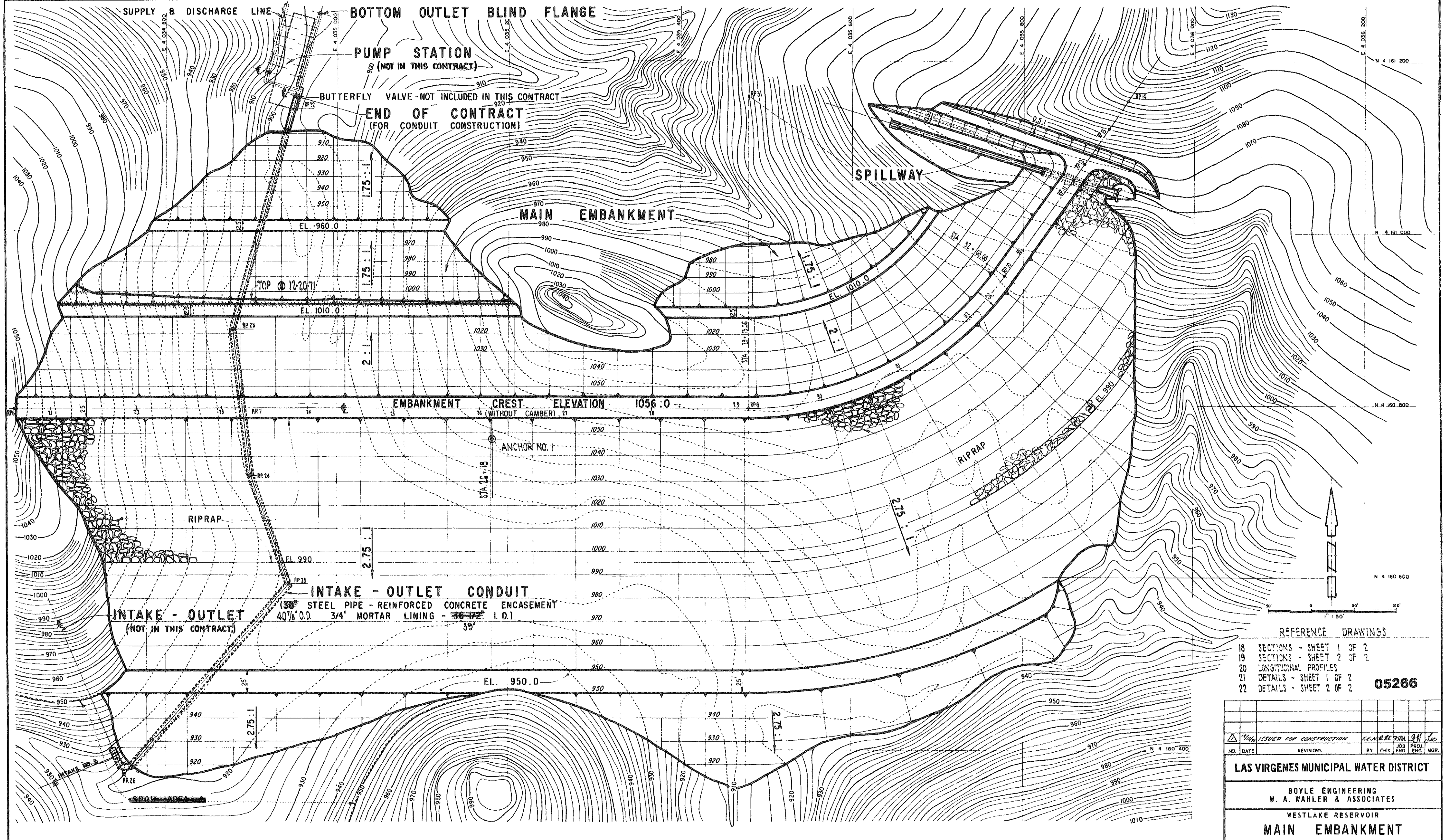
LAS VIRGENES MUNICIPAL WATER DISTRICT

BOYLE ENGINEERING
W. A. WAHLER & ASSOCIATES

WESTLAKE RESERVOIR

RESERVOIR PLAN

DESIGNED A.H.	DATE: 11-70	JOB ENG. D.F.M.	PROJ. ENG. A.H.
DRAWN H.R.	L. A. Clayton R. C. E. 9984	DRAWING NUMBER 3	REV.
CHECKED D.F.M.			
SCALE AS SHOWN			



PLAN
SCALE: 1" = 50'

REFERENCE DRAWINGS

18 SECTIONS - SHEET 1 OF 2
19 SECTIONS - SHEET 2 OF 2
20 LONGITUDINAL PROFILES
21 DETAILS - SHEET 1 OF 2
22 DETAILS - SHEET 2 OF 2

05266

NO.	DATE	REVISIONS	BY	CH'K	JOB ENG.	PROJ. ENG.	MGR.
1	12/11/70	ISSUED FOR CONSTRUCTION	T.E.N.	R.R.C.	DFM.	JH	Lc

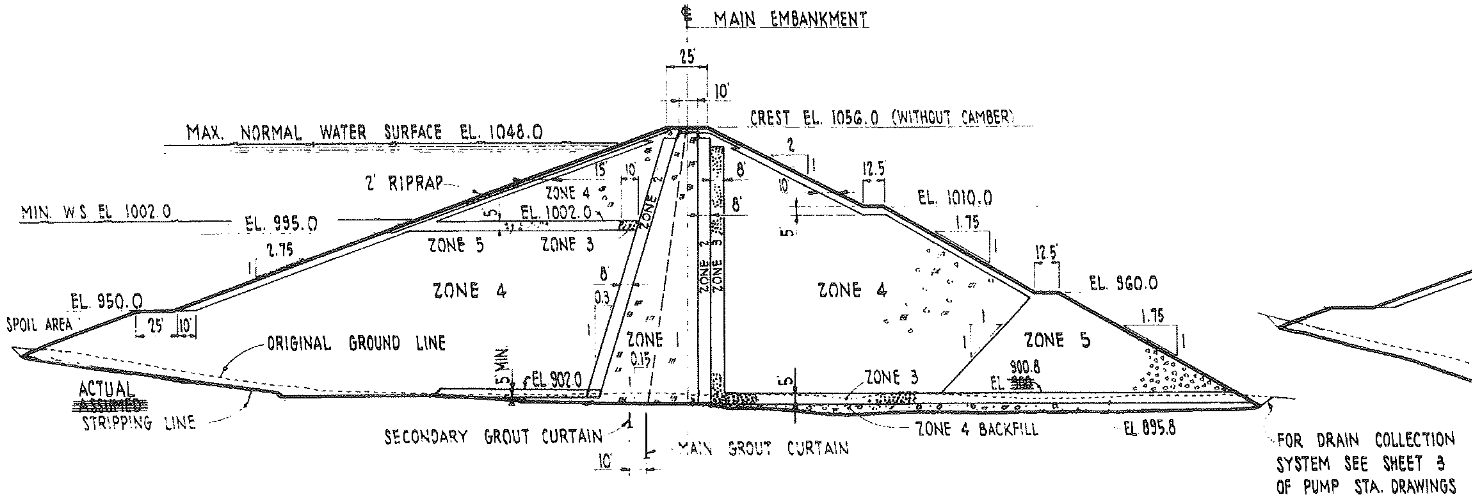
LAS VIRGENES MUNICIPAL WATER DISTRICT

BOYLE ENGINEERING
W. A. WAHLER & ASSOCIATES

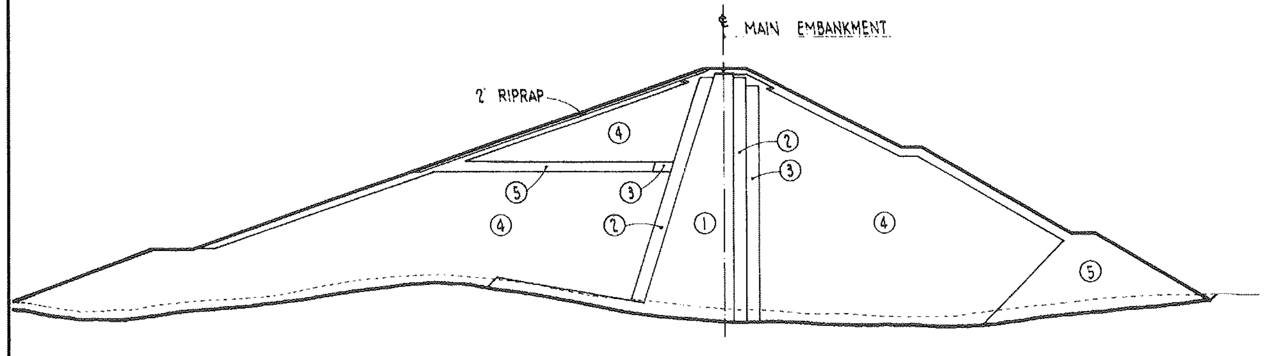
WESTLAKE RESERVOIR
MAIN EMBANKMENT
GENERAL LAYOUT

DESIGNED F.W.G. DATE: 11-70 JOB ENG. C.W.P. PROJ. ENG. JH
DRAWN Y. R.
CHECKED C.W.P.
SCALE AS SHOWN
L A Cleayto
R. C. E. 9986
DRAWING NUMBER 17
REV.

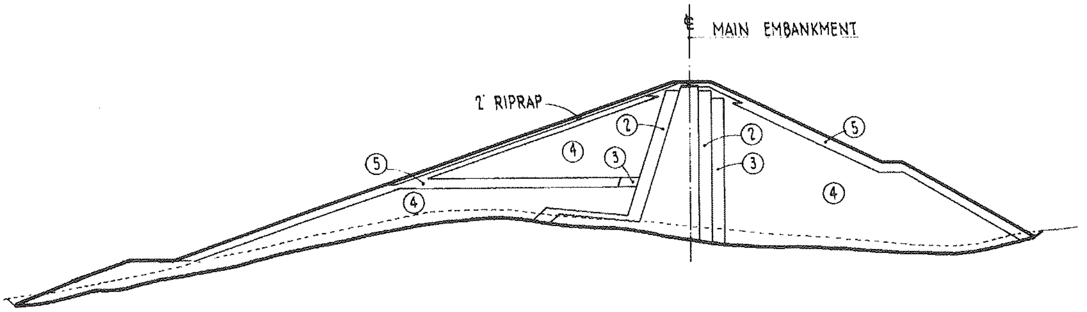
AS CONSTRUCTED
DATE 4/5/73 DFT H.H.R. CKD DFM.



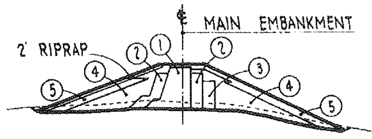
SECTION AT STA. 24+00



SECTION AT STA. 23+00

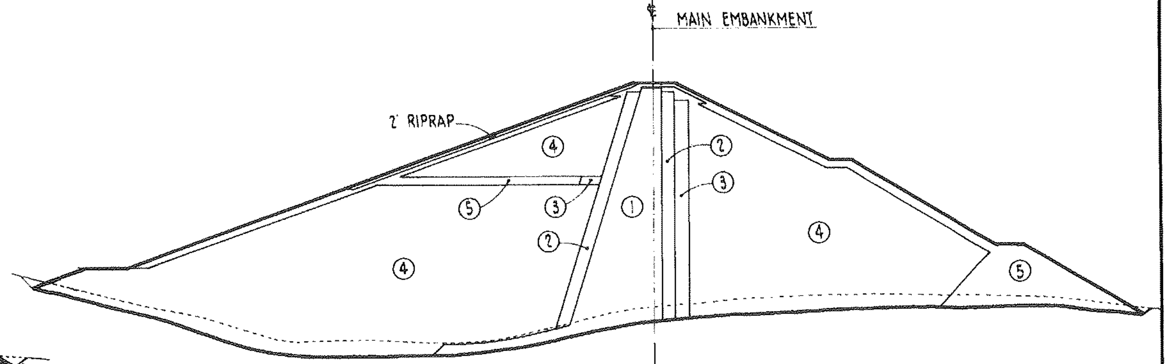


SECTION AT STA. 22+00

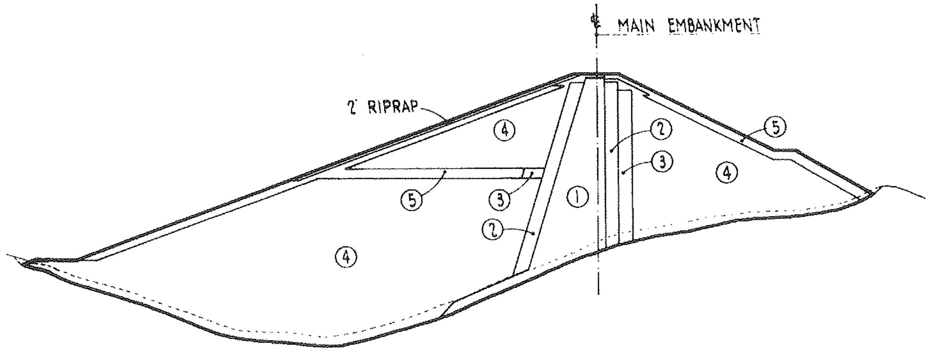


SECTION AT STA. 21+00

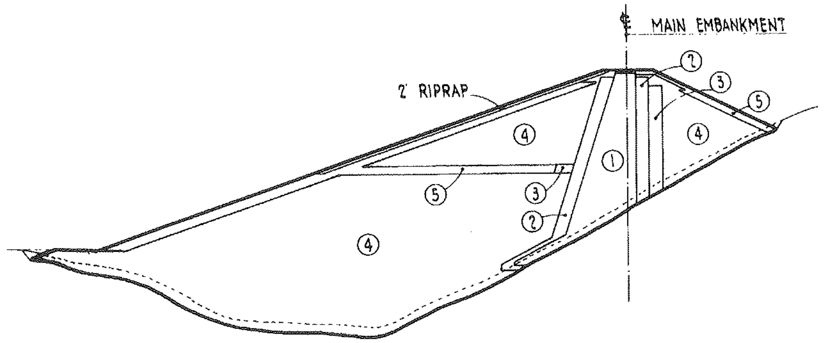
SCALE: 1" = 50'



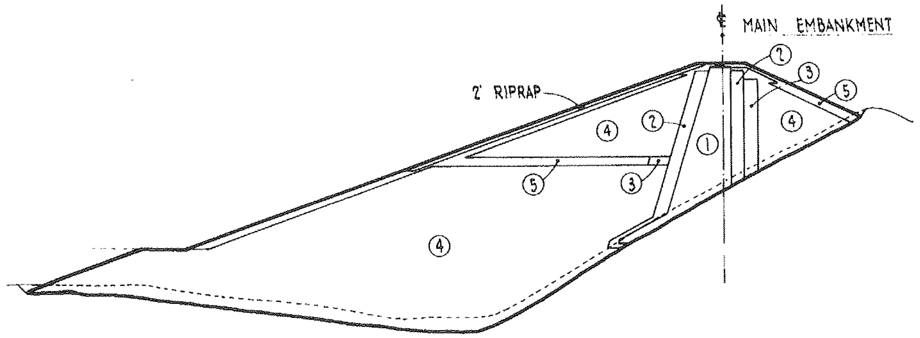
SECTION AT STA. 25+00



SECTION AT STA. 26+00



SECTION AT STA. 27+00



SECTION AT STA. 28+00

SCALE: 1" = 50'

NOTES

1. Main and secondary grout curtains are shown only on Sections at Sta. 24+00. Criteria for grout curtain locations over remainder of dam alignment are as shown on that section.

05268

REFERENCE DRAWINGS

FOR REFERENCE DRAWINGS SEE DRAWING NO. 17

4/5/73 HHR DFM

50' 0 50' 100'
1" = 50'

NO.	DATE	REVISIONS	BY	CH'K	JOB ENG.	PROJ. ENG.	MGR.
△1	12/10/70	ISSUED FOR CONSTRUCTION	T.E.M.		D.F.M.		

LAS VIRGENES MUNICIPAL WATER DISTRICT

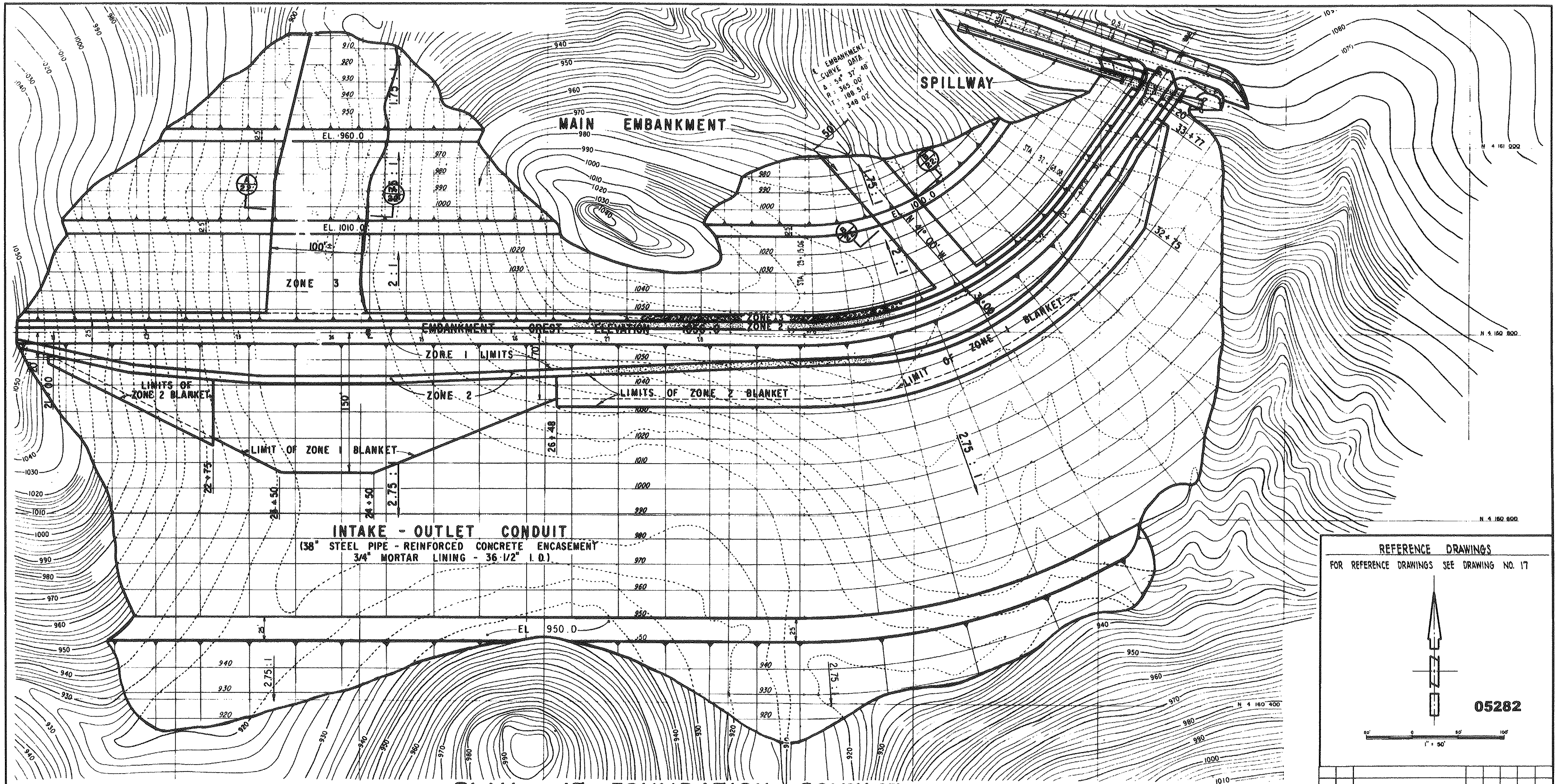
BOYLE ENGINEERING
W. A. WAHLER & ASSOCIATES

WESTLAKE RESERVOIR

MAIN EMBANKMENT

SECTIONS - SHEET 1 OF 2

DESIGNED F.W.G.
DATE: 11-70
JOB ENG. C.W.P.
PROJ. ENG.
DRAWN H.R.
CHECKED C.W.P.
SCALE AS SHOWN
L. A. Clayton
R.C.E. 9986
DRAWING NUMBER 18
REV.



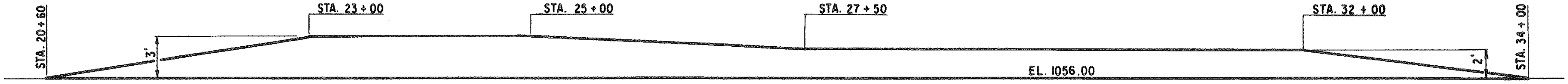
REFERENCE DRAWINGS

FOR REFERENCE DRAWINGS SEE DRAWING NO. 17

PLAN ~ AT FOUNDATION CONTACT

SCALE: 1" = 50'

NOTE: ALL CONTOURS INDICATED ARE ORIGINAL BEFORE STRIPPING.



CAMBER DIAGRAM

HORIZ. SCALE: 1" = 20'
VERT. SCALE: 1" = 4'

AS CONSTRUCTED
DATE 4/5/73 DFT H.H.R. CKD DFM

NO.	DATE	REVISIONS	BY	CH'K	JOB ENG.	PROJ. ENG.	MGR.
1	12/11/70	ISSUED FOR CONSTRUCTION	T.E.M.	S.E.	DFM		

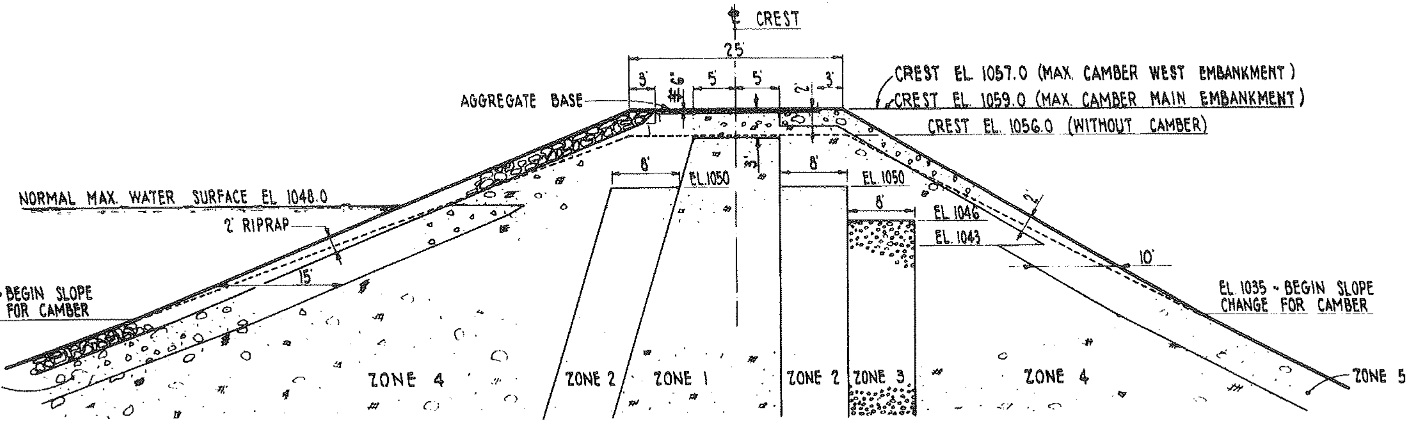
LAS VIRGENES MUNICIPAL WATER DISTRICT

BOYLE ENGINEERING
W. A. WAHLER & ASSOCIATES

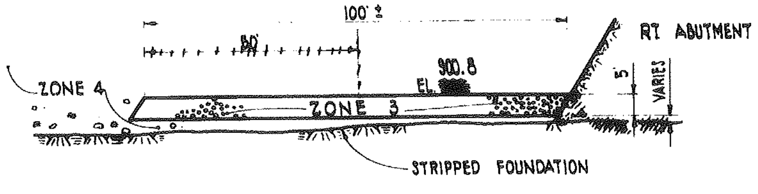
WESTLAKE RESERVOIR

MAIN EMBANKMENT
DETAILS - SHEET 1 OF 2

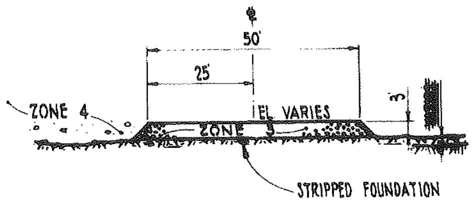
DESIGNED F.W.G. DATE: 11-70 JOB ENG. C.W.P. PROJ. ENG.
DRAWN H.R.
CHECKED C.W.P.
SCALE AS SHOWN
L. A. Clayton
R.C.E. 9986
DRAWING NUMBER 21
REV.



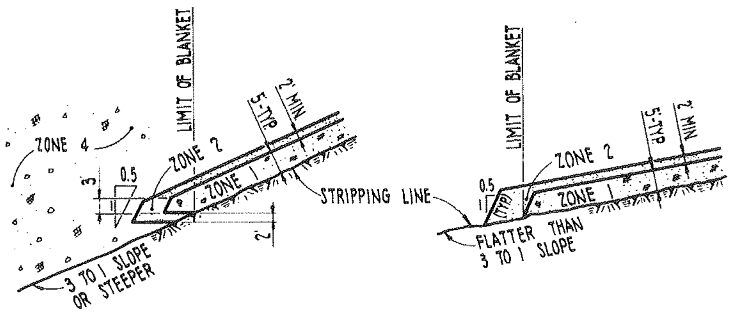
WEST & MAIN EMBANKMENT CREST DETAIL
SCALE: 1" = 10'



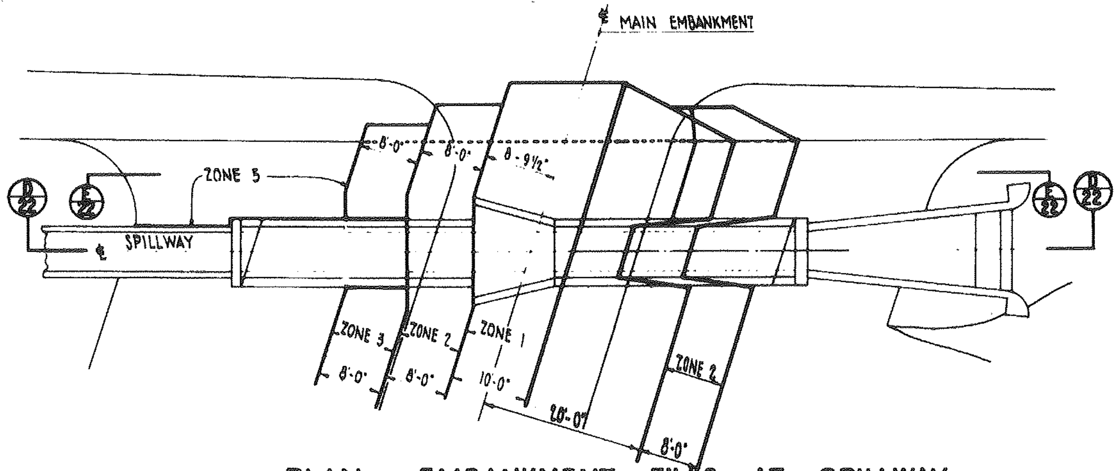
SECTION (A/22)
SCALE: NONE



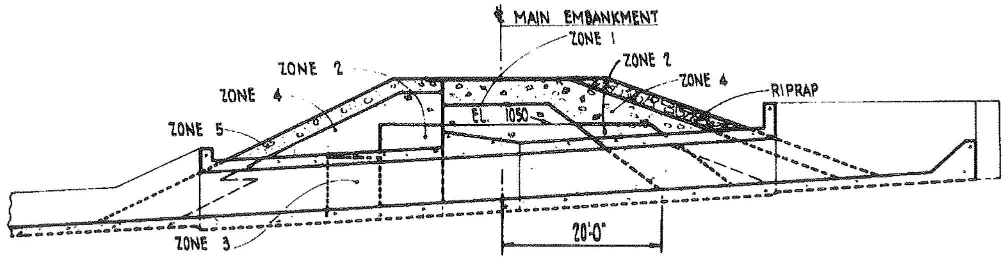
SECTION (B/22)
SCALE: NONE



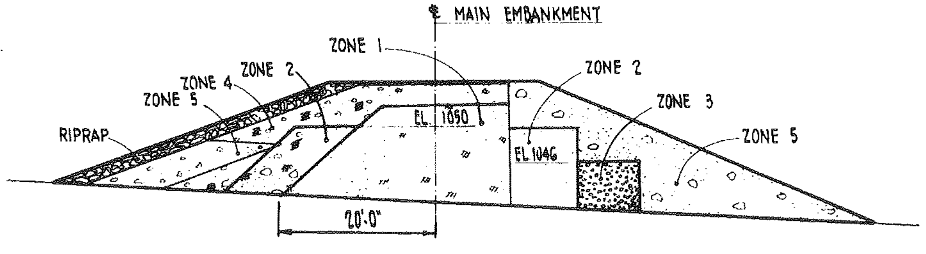
UPSTREAM BLANKET DETAILS (C/22)
SCALE: NONE



PLAN ~ EMBANKMENT FILLS AT SPILLWAY
SCALE: 3/32" = 1'-0"



SECTION (D/22)
SCALE: 3/32" = 1'-0"



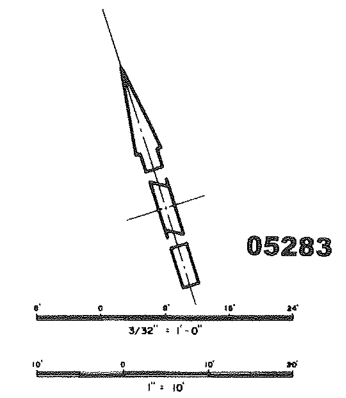
SECTION (E/22)
SCALE: 3/32" = 1'-0"

AS CONSTRUCTED
DATE 4/5/73 DFT K.K.R. CKD DFM

NOTES

1. Aggregate base shall meet Class 2 gradation as required by State of California Specification.

REFERENCE DRAWINGS
FOR REFERENCE DRAWINGS SEE DRAWING NO 17



05283

NO.	DATE	REVISIONS	BY	CHK	JOB ENG.	PROJ. ENG.	MGR.
△	12/17/70	ISSUED FOR CONSTRUCTION	T.E.N.	J.H.S.	DFM	GH	

LAS VIRGENES MUNICIPAL WATER DISTRICT

BOYLE ENGINEERING
W. A. WAHLER & ASSOCIATES

WESTLAKE RESERVOIR
WEST & MAIN EMBANKMENT
DETAILS - SHEET 2 OF 2

DESIGNED F.W.G. | DATE: 11-70 | JOB ENG. C.W.P. | PROJ. ENG.
DRAWN K.R.
CHECKED C.W.P.
SCALE AS SHOWN
L.A. Clayton
R.C.E. 9986
DRAWING NUMBER 22
REV.