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Two Case Histories of Blast- & Traffic-Induced Vibrations on the Stability of Burrows of Endangered Sensitive Ground Dwelling Animals

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TWO CASE HISTORIES OF BLAST- & TRAFFIC-INDUCED VIBRATIONS ON THE STABILITY OF BURROWS OF ENDANGERED SENSITIVE GROUND DWELLING ANIMALS

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ABSTRACT

Two case histories are presented where jurisdictional authorities expressed a concern regarding the impact of blast and construction traffic induced vibrations on the stability of the burrows of endangered ground dwelling species. The first case history involved the use of explosives proposed to be used for a seismic survey in the vicinity of desert tortoise burrows. The concern was that the use of explosives in the vicinity of a tortoise burrow could cause the collapse of an occupied burrow potentially trapping the tortoise within the burrow. Field tests were performed by constructing artificial tortoise burrows and inducing progressively higher vibration levels near the test burrows while observing the stability of the burrow. The data obtained from the tests were used to develop a site-specific attenuation relationship and vibration amplitude-burrow collapse relationship. These relationships were used to establish safe distance criteria for the use of explosives.

The second case history involved the effect of heavy haul-truck traffic induced vibrations on the stability of San Bernardino Kangaroo Rat (SBKR) burrows. The jurisdictional authority imposed a mitigation area requirement equal to 100-ft. on either side of the almost 2-mile long haul roadway. This resulted in a significant cost impact on the project. Initially, an evaluation was made using the results of the tortoise study for vibration amplitude-burrow stability criteria on the premise that the wide low tortoise burrows would tend to be less stable than the smaller round SBKR burrows. This relationship was used together with attenuation relationships for the heavy haul-trucks considering soil type, the road roughness, truck weight, number of trucks, and trucks speed to evaluate the required mitigation area. The initial analysis indicated that 3-ft. on either side of the roadway would be acceptable to define the mitigation area instead of the 100-ft imposed by the jurisdictional authority. The results of the initial evaluation were discussed with personnel representing the jurisdictional authority and a compromise mitigation distance of 10-ft on either side of the haul road was negotiated, contingent on the results of field-testing. The field testing was completed by excavating 36 artificial SBKR burrows along the haul route, inserting split sample tubes into the burrows, monitoring vibrations induced by truck traffic at 5-ft. and 10-ft. from the road, removing the split sample tubes after one hour of truck traffic (25 to 35 trucks), and measuring the volume of soil collected in the split tubes. It was found that less than 10% of the volume of the burrow hole was collected in the sample tubes and the test results were found acceptable by the jurisdictional authority.

The paper provides a tabulation of all vibration measurements, photos or diagrams of sampling and test layouts, the basis for estimating vibration amplitudes, and the conclusions reached from each case history.

INTRODUCTION

Two case histories of evaluating the impact of vibrations on the stability of endangered, sensitive ground dwelling animals are presented. At first blush, this may seem to be an unusual set of case histories; however, at a time in history when increased urbanization more and more encroaches on the habitat of animals, it is not surprising that civil projects become impacted and impact endangered species. These endangered species impacts often cause significant constraints to projects and must be taken seriously. Various jurisdictional authorities have imposed constraints on projects that can be expensive and are often times are without basis in part due to lack of data. The purpose of this paper is to provide the beginnings of a data base so as to put the actual impacts of construction induced vibrations on sensitive habitat in perspective.

The first case history involves the sensitivity of a desert tortoise's burrow to sustain damage due to blasting vibrations. In this particular case the blast induced vibrations were associated with small explosive charges used to conduct deep seismic refraction surveys. The purpose of the investigative work was to set safe distances to tortoise burrows located by project scientists such that the explosive charges could be set off without negatively impacting the stability of tortoise burrows in the area. The second case history covers the stability of the San Barnardino kangaroo rat (SBKR) burrow in close proximity to a heavy haul route for a large pipe line construction project. In this case, the jurisdictional authority imposed a 100-ft. mitigation distance from the side of a two-mile long route for which the owner had to pay mitigation costs. The case history describes an evaluation and testing program that reduced the mitigation area imposed by the jurisdictional authority down to 10% of what was initially required.

CASE HISTORY 1
DESERT TORTOISE BURROW SENSITIVITY TO VIBRATIONS

This case history addresses potential impacts on the desert tortoise, a species that is federally and State of California listed as threatened, associated with proposed seismic refraction surveys on lands near Hayfield Lake that are owned by Metropolitan Water District of Southern California (Metropolitan), as shown on Fig. 1. Seismic refraction surveys are proposed as a part of the field investigations to sense the depth to bedrock and the groundwater table and to assess the possible presence of groundwater barrier forming faults in the Hayfield Lake areas.

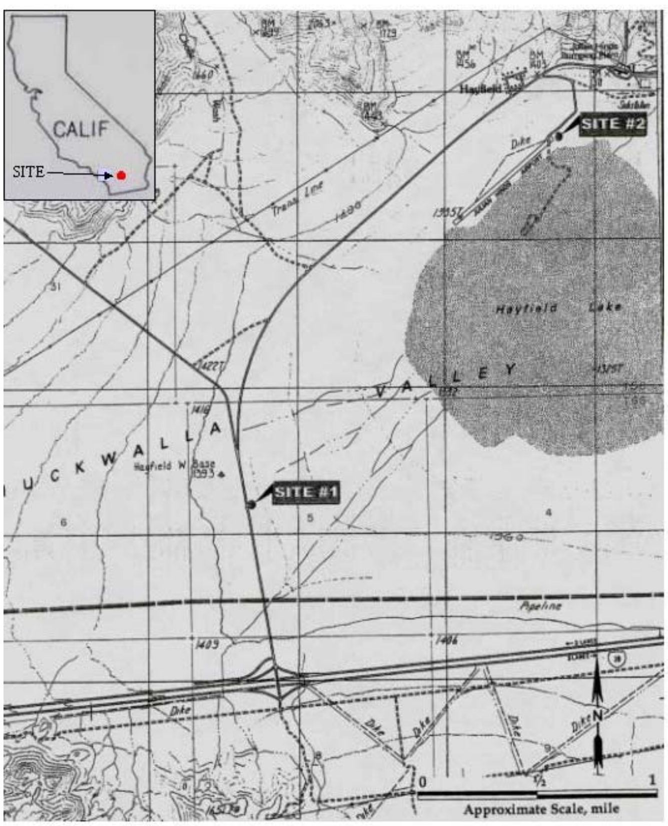

Fig. 1. Location of tortoise burrow stability investigation site.

Three seismic lines were proposed to be placed entirely on Metropolitan-owned land, as illustrated in Fig. 1. These lines were approximately 7,500-10,000 feet long and required the use of explosives. In all, a total of seven shot points using explosives were required for the survey. At each shot point, an approximately 25-foot-deep hole was to be drilled, a 15-pound explosive charge was to be placed within each hole, and each shot hole was to be stemmed to the surface with the drill cuttings. The charges were to be detonated individually and seismic vibrations created by the detonations were to be recorded via a series of geophones placed along each line.

Methodology for Tortoise Vibration Study

The general biological characteristics and the presence of desert tortoise within the general survey area were determined by biological studies conducted in late summer and early fall 1998. A radius of approximately 350 feet around each shot point was surveyed in May of 1999 to identify tortoise scat, live tortoises, potential burrows, and any other signs of tortoise activity. All tortoise signs and potential burrows were mapped and recorded on data sheets. The area along each seismic line was also characterized as to its value as tortoise habitat.

A ground motion sensitivity test was conducted to determine the potential for impacts on tortoise burrows associated with the detonation of explosive charges at the shot point. Two simulated tortoise burrows were constructed in the general survey area, as shown of Figs. 2 and 3. Vibrations produced by a spring driven hammer were measured at various distances from each constructed burrow, as shown on Fig. 4, and the impacts on these burrows were measured both through the use of particle velocity sensing transducers and observations by biologists.

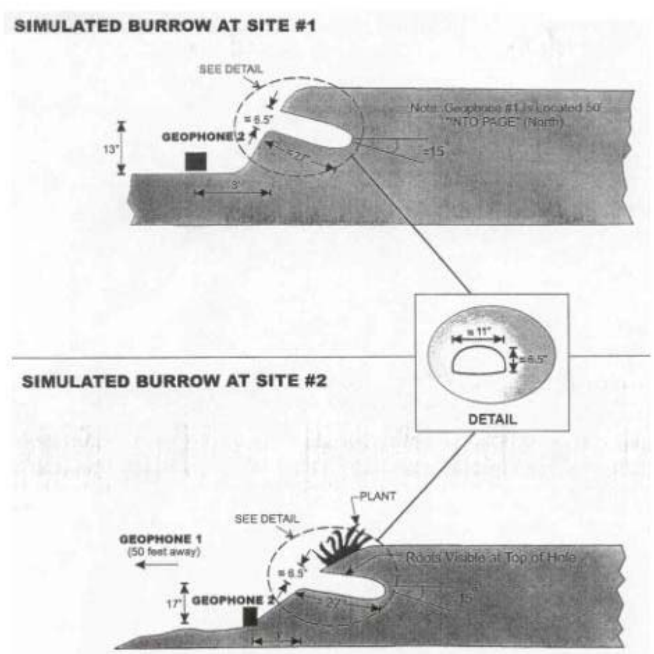

Fig. 2. Cross-sections of simulated tortoise burrows.

Fig. 3. Photo of simulated tortoise burrow.

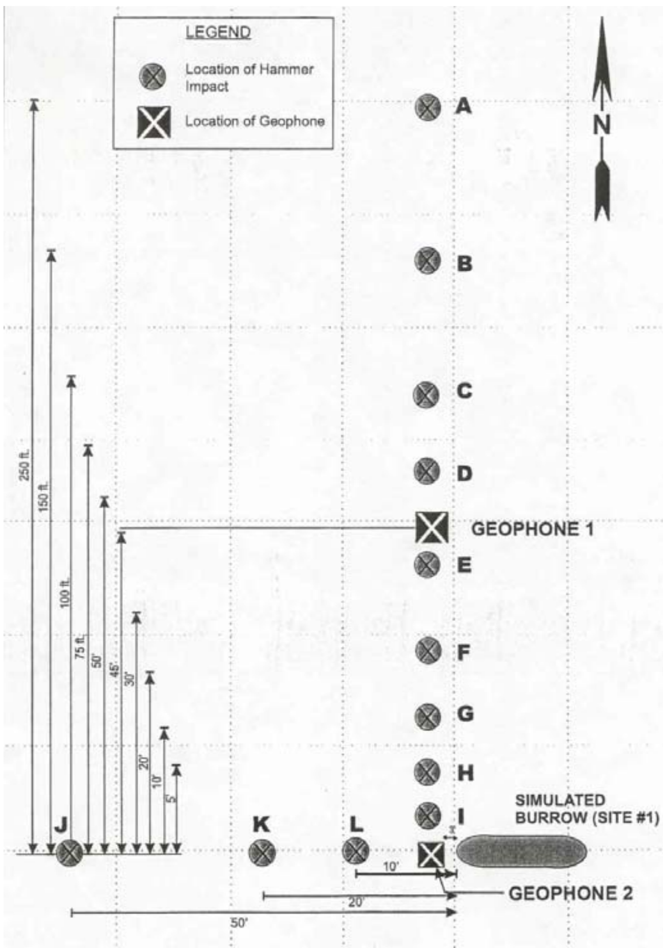

Fig. 4. Vibration monitoring layout for tortoise burrow tests.

To complete the ground motion sensitivity test, two test sites that represented the range in soil types that are found in the area around the proposed shot points and that would be soil types and locations where tortoises might burrow were identified by a biologist. The approximate location of these two test sites, designated as Site #1 and Site #2, are shown on Figure 1.

At each test location a biologist excavated by hand, a hole to simulate a tortoise burrow. The simulated burrows at Site #1 and Site #2 were excavated 27 inches deep at an angle about 15° below horizontal, as shown on Fig. 2. At Site #1, the simulated burrow was excavated in relatively loose gravely sands in a small road berm that bordered the east side of the paved road into the Hinds Pump Station. The excavated Site # 1 simulated burrow was about 6 1/2 inches high and about 11 inches wide, as shown on Fig. 2. At Site #2, the simulated burrow was excavated in relatively loose gravely sands in a man-made dike that flanks the northern end of the abandoned airway strip near the edge of Hayfield Lake. The Site #2 simulated burrow was dug beneath the root system of a creosote bush and was about 6 1/2 inches high and about 11 inches wide, as shown on Fig. 2. The floor of the Site #1 simulated burrow was about 13 inches above the ground at the base of the berm into which it was excavated, and the Site #2 simulated burrow was about 17 inches above relatively level ground, as shown on Fig. 2. A folded piece of paper was placed on the floor of each simulated burrow to catch soil that would fall from the roof or walls of the burrow during the ground motion sensitivity test.

At each test site, a Sprengnether Model S-6000 sensitive particle velocity sensing transducer (geophone-l) was placed on the level ground about 50 feet away from the simulated borrow, as shown on Fig. 4 for Sites #1. A second Sprengnether Model S-6000 sensitive particle velocity sensing transducer (geophone-2) was place on level ground at the base of each berm into which the simulated burrow was excavated, about 3 feet from the opening of the simulated burrow as shown on Fig. 4 for Site #1.

The transducers consist of a moving magnetic coil system, which transforms mechanical vibration to electrical signals. Vibration signals from the particle velocity sensing transducers were passed through a Honeywell 117 accudata multichannel DC amplifier and recorded on a Honeywell 1858 Oscillograph (strip chart recorder), which prints the vibration record on a moving strip of light sensitive recording paper. The system is capable of recording peak-to-peak particle velocities in the range of 0.0001 inches per second to 20 ips at frequencies from 2 to 200 hertz (Hz). All measurements were taken simultaneously at the locations of the two geophones.

A mechanical, spring driven hammer mounted to the back of a pick-up truck was used to generate the ground motions at each test site by hitting a steel plate positioned on the ground surface. The spring driven hammer consists of a 250 lb. weight that is raised hydraulically and when released is pulled down with a set of springs which upon impact generates about 3.250 ft.-lb. of energy.

As shown on Fig. 4, each simulated burrow was subjected to vibration from 12 hammer impacts at distances ranging from 250 feet to 5 feet from the simulated burrows along two perpendicular lines. Each hammer impact run is labeled by letter A through L with the simulated burrow number preceding it. For example, 1A represents the run number at simulated burrow Site #1 at hammer impact location "A" where the impact point "A". is 250 ft. away from the simulated burrow as shown on Fig. 4. Figure 5 shows a typical recording for run 2E (i.e. simulated burrow at Site #2 where the hammer impact is 45 ft from the burrow). As shown on Fig. 5, the signal from the geophone -2 was amplified by a factor of 10 times that of geophone -1 to facilitate data interpretation. The L, V, and T designation on the recording shown on Fig. 5 represents the longitudinal, vertical and transverse directions of ground motion. Longitudinal ground motion is in the direction along the line between the hammer impact point and the simulated burrow and transverse ground motion is perpendicular to the longitudinal direction for runs 1A to 1I and 2A to 2I. However, for runs 1J, 1K, 1L, 2J, 2K, 2L the transverse ground motion direction is in the direction along the line between the hammer impact point and the simulated burrow and longitudinal ground motion is perpendicular to the longitudinal direction.

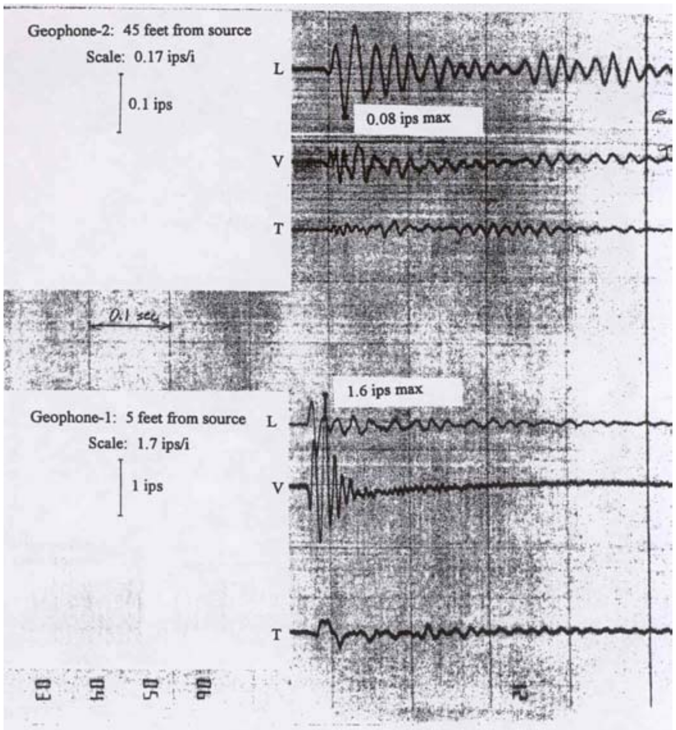

Fig. 5. Typical vibration record (2E).

The ground motions generated at each hammer "impact point" and the corresponding effects on the simulated burrows were observed and recorded by biologists by continually observing the soil that fell or did not fall on the paper placed in the simulated burrow.

Results of Tortoise Vibration Study

The vibration results for all tests, in terms of the peak vibration levels, average frequency of vibration, and the observed soil disturbance in the simulated burrows are presented in Table A-1 in Appendix A. As can be seen from Table A-1, at Site #1 no disturbance of the simulated burrow from the hammer impacts was noted for distances greater than 30 ft from the simulated burrow. For Site #2 no burrow disturbance was noted from hammer impacts at distances greater than 20 ft from the simulated burrow. Neither simulated burrow collapsed due to vibrations induced by the hammer impacts.

The interpreted data from Table A-1 are plotted on a log-log graph of peak particle velocity versus distance on Fig. 6. Also plotted on Fig. 6 is vibration level with distance line estimated to be induced by the buried 15-lb. explosive charge to- be used for the seismic refraction surveys. This 15-lb. explosive charge 1ine was constructed based on our experience with -vibrations induced by explosives, data in the literature, and on a review of this hammer impact test vibration records. Though burrow collapse did not occur due to hammer-induced vibrations, for conservatism, it was decided to select 1/2 cup of soil dislodged into the simulated burrow as a conservative estimate of burrow disturbance. For the simulated burrow in the loosest soil which is located at Site # 1, this level of burrow disturbance yields about 0.4 ips peak vibration amplitude. When considering vibrations from the 15 lb. explosive charge to be used in the seismic refraction surveys and the distance from the shot point to a tortoise burrow, on Fig. 6, this amplitude would occur at a distance of just under 150 ft. from the shot point. In discussing this with tortoise biologists, it was suggested that this distance be doubled for conservatism if a tortoise was residing in the burrow.

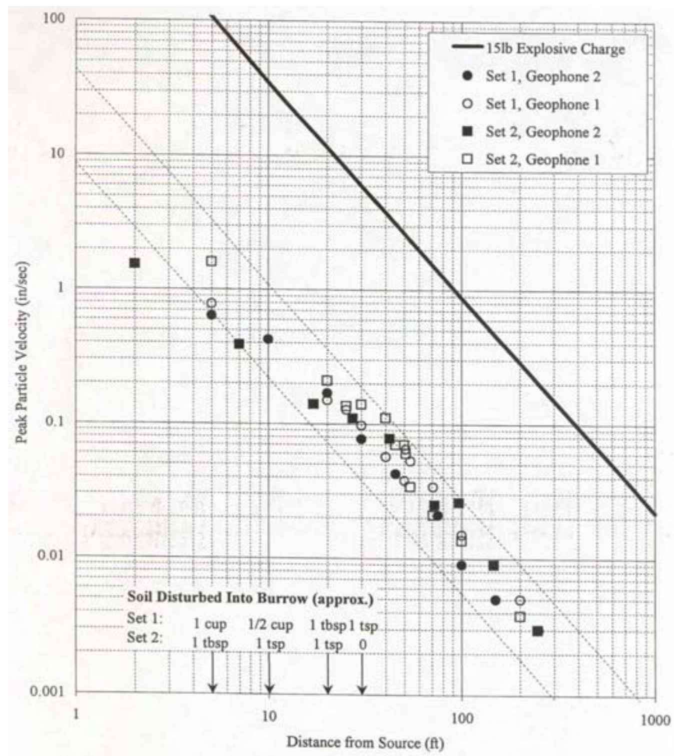

Fig. 6. Measured vibration amplitude versus distance.

Conclusions from Initial Tortoise Vibration Study

Based on the vibration measurements made using the spring driven hammer, it was found that 0.4 ips peak particle velocity conservative vibration level that could affect a tortoise burrow. To demonstrate how conservative the 0.4 ips criteria is, it was noted that the first time the hammer impact caused. 0.4 ips peak particle velocity at the Site #1 simulated burrow, 1/2 cup of soil fell into the simulated burrow the second time the hammer impact caused 0.4 ips peak particle velocity at Site #1 simulated burrow only 2 tbs. of soil fell into the simulated burrow. Further, in the simulated burrow at Site #2 the 0.4 ips peak particle velocity at the Site #2 simulated burrow caused only 1 tsp. of soil to fall into the simulated burrow.

Using the 0.4 ips amplitude criteria, this means keeping the shot point for the seismic refraction line at least 150 ft. away from any tortoise burrow. Further, for conservatism, the shot point should be kept twice this distance or 300 ft. from a burrow with a tortoise in residence. Therefore, it was recommended that the area around shot points (15 lb. explosive charge) for seismic refraction surveys be inspected for a radial distance of 300 ft. for tortoise burrows. If an empty burrow is found within 150 ft. of the shot point, or a tortoise in residence burrow is found within 300 ft. of the shot point, the shot point should be moved so that the 150 ft. and 300 ft. distances are maintained.

Results of Subsequent Tortoise Vibration Measurements and During Seismic Survey

Following the ground motion sensitivity study discussed above, three seismic refraction surveys using explosives were completed in the Hayfield Lake area. During the surveys, particle velocities at the surface were recorded at various distances from the shots. Additionally, two simulated tortoise burrows and one old (abandoned) tortoise burrow were observed at various distances from the shot points.

The shots consisted of 15 pounds of explosives (water gel) with ½ pound PETN primer buried approximately 25 feet deep in 3- to 4-inch diameter boreholes. During the seismic surveys, surface vibration measurements were taken at various dstances to help confirm the predictions made on Fig. 6. For each shot, up to three geophones were placed at various distances from the shot, ranging from 30 feet to 160 feet. The peak particle velocities were measured and are presented in Table A-2, which presents the results, and Fig. 7, which presents the results plotted along with the predicted values. The predicted velocity line is shown to provide an upper bound for the data collected in the study.

Additionally, three burrows (one natural, two simulated) were observed during blasting. The simulated tortoise burrows were located 30 feet and 150 feet from the shot. Vibration measurements made at the closer simulated tortoise burrow showed a peak particle velocity of 3.2 ips, resulting in approximately ½ cup of soil falling into the first foot of the simulated burrow. The simulated tortoise burrow located further away showed no sign of distress due to the shot. The natural burrow of unknown origin, which had no sign of a tortoise in residence, was located 58 feet from one shot. This burrow remained intact enough to observe during the shot. Vibration measurements showed a peak particle velocity of 1.9 ips; however, no impact was observed at the burrow.

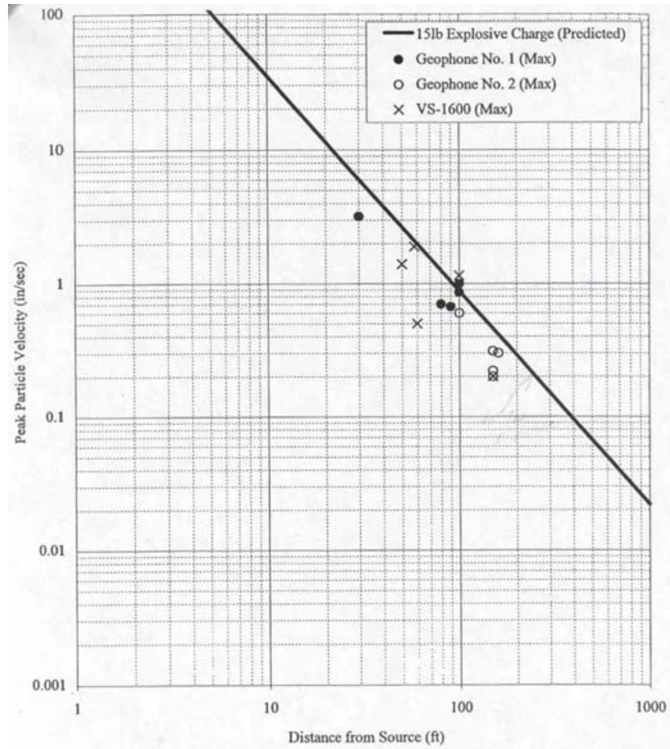

Fig. 7. Summary of vibration data collected during seismic surveying.

Conclusions of Tortoise Vibration Study

The results from the surface vibration studies during seismic testing show that the estimates for vibrations induced by subsurface blasting are lower than predicted in Fig. 6. At a distance of 30 feet, approximately ½ cup of soil fell into a simulated tortoise burrow dug into loose soil, and at a distance of 150 feet, no soil fell into a simulated tortoise burrow dug into similar soil. A natural burrow at a distance of 58 feet had little to no damage due to a similar blast. Based on these results, the conclusions drawn from the initial study were conservative. Revising the 0.4 ips to 1 ips maximum velocity based on the tests as a limiting velocity, the distance to a blast point could be reduced to approximately 100 feet. For conservatism, the shot should be kept twice this distance, or 200 feet, from a burrow with a tortoise in residence.

CASE HISTORY 2
SBKR BURROW SENSITIVITY TO VIBRATIONS

This case history summarizes the results of a San Bernardino Kangaroo Rat (SBKR) (*Dipodomys merriami parvus*) burrow vibration sensitivity test that was performed in the Santa Ana River wash area along haul roads for the Mentone Pipeline segment of the Inland Feeder Project, as located on Fig. 8. Initially, the U.S. Fish and Wildlife Service (USFWS) specified that Metropolitan was to provide mitigation one hundred feet on either side along the 2-mile long haul road, shown on Fig. 8. As a result of this requirement, the authors evaluated the requirement by using the roadway roughness, vehicle weight, vehicle maximum speed and estimated attenuation characteristics together with data documented for heavy bus traffic in Barneich (1985) and the results of the tortoise burrow stability tests discussed in the previous section. The resulting analysis indicated that the heavy truck traffic should not affect the stability of SBKR burrows more than three feet from the side of the roadway. As a result of this analysis, the USFWS reduced the 100-ft. mitigation requirement to 10-ft. contingent on the results of testing described below.

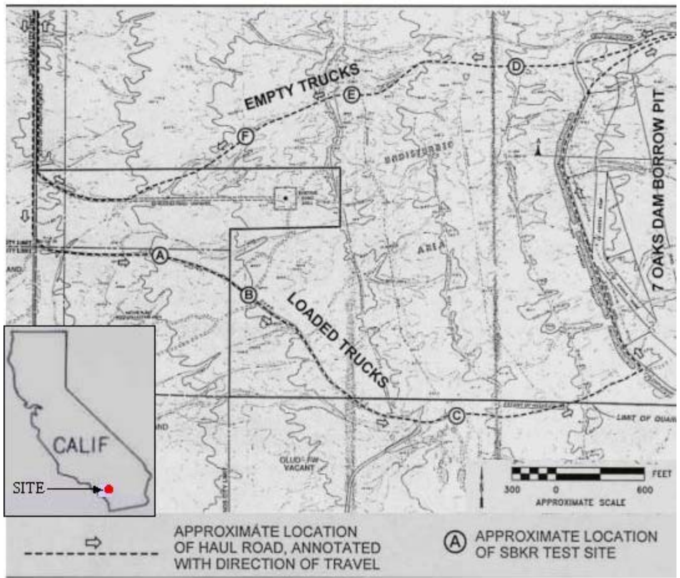

Fig. 8. Location of SBKR burrow stability investigation site.

The subject test was completed in compliance with a letter dated August 2, 2000 from the U.S. Department of Interior - Fish and Wildlife Service to the U.S. Army Corps of Engineers (Corps.). The importance of the test is that the SBKR is a federally endangered species and the Santa Ana River (SAR) wash is one of the primary areas of remaining occupied habitat for this species. The purpose of this test was to evaluate the effects of vibrations induced from haul trucks on the stability of SBKR burrows.

Methodology of SBKR Vibration Study

General Vibration sensitivity tests were performed between August 21, and 23, 2000 at six haul road locations (designated "A" through "F"), as shown on Fig. 8. Tests "A" through "C" were performed along the south haul road alignment, along which haul trucks traveled loaded with spoil material from the Mentone pipeline trench excavation. Tests "D" through "F" were performed along the north haul road, along which haul trucks traveled empty (no load).

At each of the six test locations, the vibration test procedure included the following:

1. Construct artificial SBKR burrows.
2. Insert and remove sample tubes before and after truck hauling operations and measure the amount of soil collected in the sample tube at the end of the test period.
3. Measure vibrations during truck hauling operations.

These steps are described in more detail below.

Artificial SKBR Burrow Construction

Six artificial SBKR burrows were constructed at each of the six test locations for a total of 36 burrows. At each test location, three burrows were constructed at an offset of 5 feet from the edge of the haul road, and three burrows were constructed at an offset of 10 feet from the edge of the haul road. Burrows at test location "A" were constructed on 8/21/00 and 8/22/00, locations "B" and "C" were constructed on 8/21/00, and locations "D" through "F" were constructed on 8/22/00. The relative locations of the burrows at Location A are shown with round solid dots on Fig. 9. Similar test layouts were made for the other five locations (B through F).

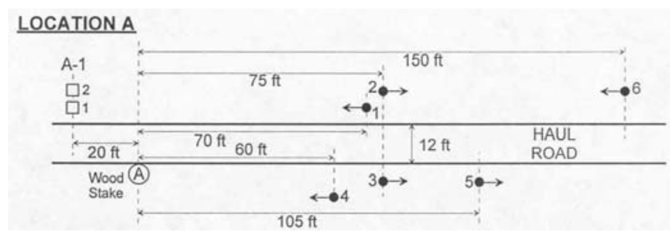

Fig. 9. Test layout for Location A.

Because the project personnel are aware of no studies of SBKR burrow depths or structure, the depth of the artificial SBKR burrows was set based on studies conducted in the desert on another kangaroo rat subspecies (*D.merriami merriami*) which was considered to be generally appliable to the SAR wash area based on soil and general environmental conditions. Data from a paper by C.J. Kenagy (Ecology 54(6); 1201-1219) indicate that the shallowest "resting" burrows for *D.m.merriami* were 5 cm deep. Burrow nest depths ranged from 26 to 175 cm (mean 98 cm) in this study. Temperature seemed to be an important determinant of the nesting depth with deeper nesting depths associated with higher surface temperatures. Considering the SAR wash has abundant boulders and cobbles that could lead to more difficult burrow excavation than that in the fine grained less rocky soils of the desert environment, possibly coupled with the lower surface temperatures expected in the SAR wash compared to the desert, it is likely that the burrow depths would be less for the SBKR than the *D.m. merriami*. The artificial burrows constructed as described below extended from the ground surface to a depth of between 40-60 cm. This depth range was judged to be appropriate for the SBKR vibration testing. The soils at the specific selected vibration test locations were generally sands with small amounts of silt, clay and gravel with abundant cobble and boulder size rock, and are considered to be representative of the soil conditions along the entirety of both south and north haul roads.

Each artificial SBKR burrow was constructed in two steps. First, a hole was drilled at an angle of 30 degrees from horizontal with a 2-inch diameter by 3-foot long steel power auger [Little Beaver (Livingston Texas) Model 5H Earth Drill], as shown in the photo on Fig. 10. Second, all loose soil cuttings were sucked out of the burrow with a 2-inch diameter by 3-foot long vacuum tube (powered by a 3.25 HP shop Vacuum cleaner). All burrows were oriented parallel to the road, and are shown with an arrow indicating the orientation of the burrow on Fig. 9 for Location A. Also, the burrows were numbered so that odd numbered burrows are located at a distance of 5-feet from the edge of the road and even numbered burrows are located at a distance of 10-feet from the edge of the road.

Fig. 10. Drilling simulated SBKR burrow.

Sample Tube Procedures for SBKR Vibration Study

The sample tubes consisted of two-nested 2-inch diameter by 36.5-inch long split clear plastic tubes with orange plastic end caps, as shown in the photo on Fig. 11. The sample tubes were installed in three steps. First, the nested sample tube pairs were set into the burrows the night before the test (except in three burrows at location "A", where the tube pairs were installed the same day as the test). The tubes were generally set in the burrows so that 2.5-inches of the sampling tube was left sticking out of the burrow. This would yield a nominal minimum volume of a burrow of about 106 cubic inches (2-inch diameter by 34-inches long). Second, the inner sample tube was retrieved just prior to the start of the test the next morning, to remove residual soil which may have collapsed overnight and to eliminate most of the soil existing in the sample tube at the beginning of the test. Third, at the conclusion of the test, the remaining sample tube was removed and any soil it collected was measured. Typically, very little soil collapsed into the sample tubes due to the disturbance created by the installation and removal of the sample tubes. The installation times of the nested sample tubes and subsequent removal of the inner sleeve tube are tabulated on Table A-3 in Appendix A.

Fig. 11. Sample tube.

SBKR Vibration Measurements

Vibration measurements were made at the locations shown by the open squares on Fig. 9 for Location A. As shown on Fig. 9, measurements were made at offsets of 5 (no. 1) and 10 feet (no. 2) from the edge of the haul road. As shown on Fig. 9, vibration measurement pairs at 5 and 10 foot offsets were made at one site at locations "A" (A1) and "B" (B1), due to limitations in access to off-road locations for a vehicle. Similar conditions existed at the remaining five test locations B through F.

Vibration measurements were made using two Sprengnether Model S-6000 particle velocity sensitive transducers (geophones), a Honeywell 117 Accudata multi-channel DC amplifier, and a Honeywell 1858 Oscillograph (strip chart recorder). A typical layout of the geophones at 5 and 10 foot offset from the edge of the haul road is shown in the photo on Fig. 12, which shows a loaded truck passing by a geophone pair. Each geophone measures particle velocity vs. time in three orthogonal directions (longitudinal, vertical, and transverse). The geophones were oriented such that the longitudinal direction pointed north or approximately perpendicular to the direction of travel along the haul roads. The geophone pairs (5 feet and 10 feet from the edge of the road) measure vibration-time histories simultaneously. A typical vibration record for a test is shown on Fig. 13. The maximum peak particle velocity and frequency of the vibration data was reduced from the strip chart records for each truck passage that was recorded, as shown on Fig. 13.

Fig. 12. Photo of typical geophone layout with haul truck in background.

Results of SBKR Vibration Study

Vibrations induced by truck traffic were measured during two test periods. During the first test period, vibrations were measured at monitoring points along the south road (locations “A” through “C”) on August 22, 2000. During the second period vibrations were measured at monitoring points along the north road (locations “D” through “F”) on August 23, 2000. The cumulative number of trucks passing the sites during these two test periods is plotted on Fig. 14. Also, the number of trucks and the elapsed test time is tabulated for each location on Table A-3. Table A-3 shows that test durations ranged from 1 hour and 4 minutes to 1 hour and 46 minutes.

Volvo A35 haul trucks ran loaded with rock and soil along the south haul road at speeds between 15 and 20 mph and empty along the north haul road at speeds between 25 and 30 mph. These speeds were somewhat faster than normal to simulate the most severe vibration conditions (vibration amplitude increases with increasing truck speed – Barneich 1985). The road roughness was reviewed by visual inspection and found to be relatively smooth due to the effect of truck traffic and daily maintenance by a blade. The roughness was also evaluated by an observer riding in the cab of the truck during one circuit. During this ride, it was noted that on the south and north roadways the roughest ride along the route was experienced at locations B and F, which were also the locations where maximum speeds were achieved. The results of the vibration measurements are tabulated in Table A-4 in Appendix A.

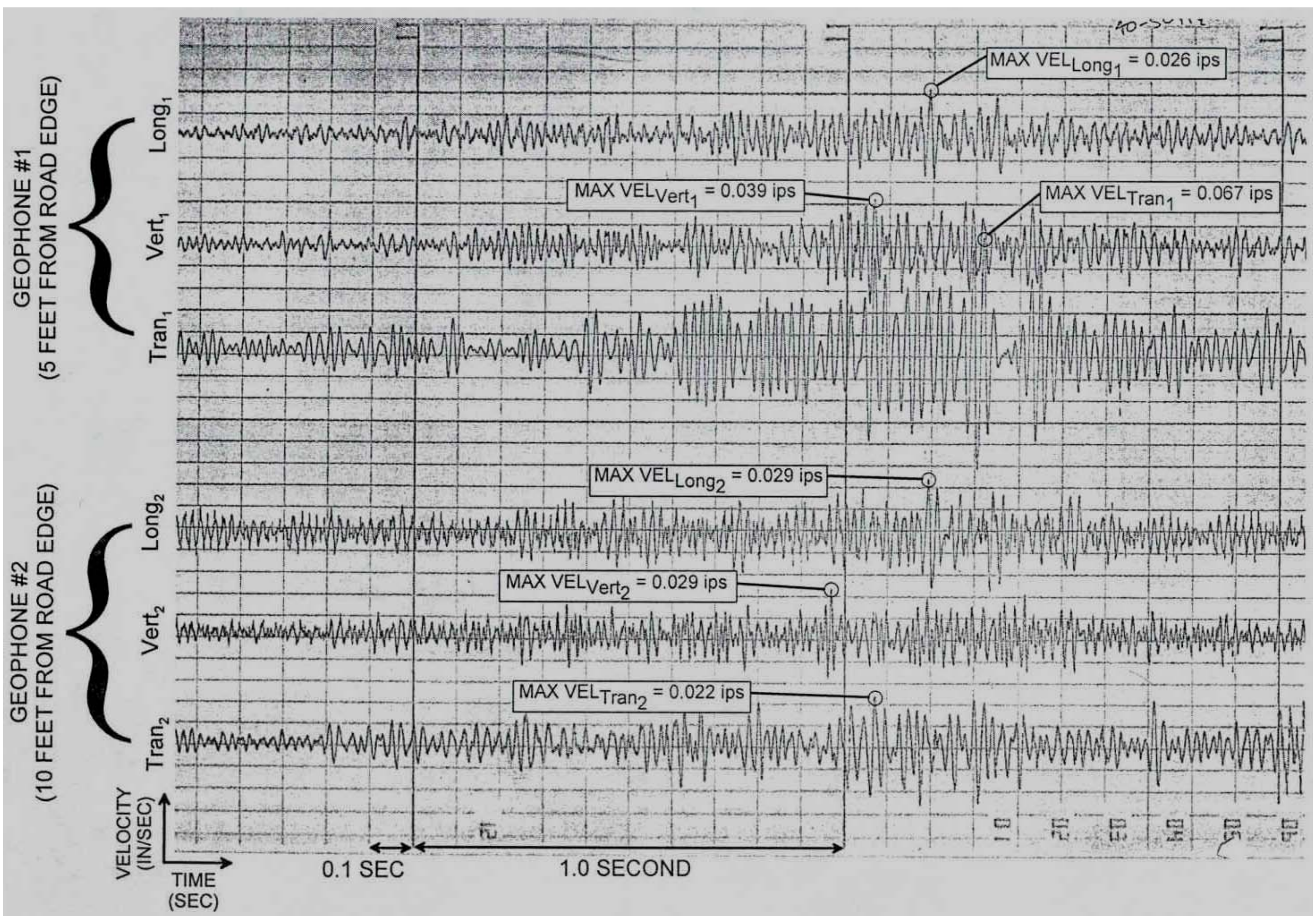

Fig. 13. Typical vibration record.

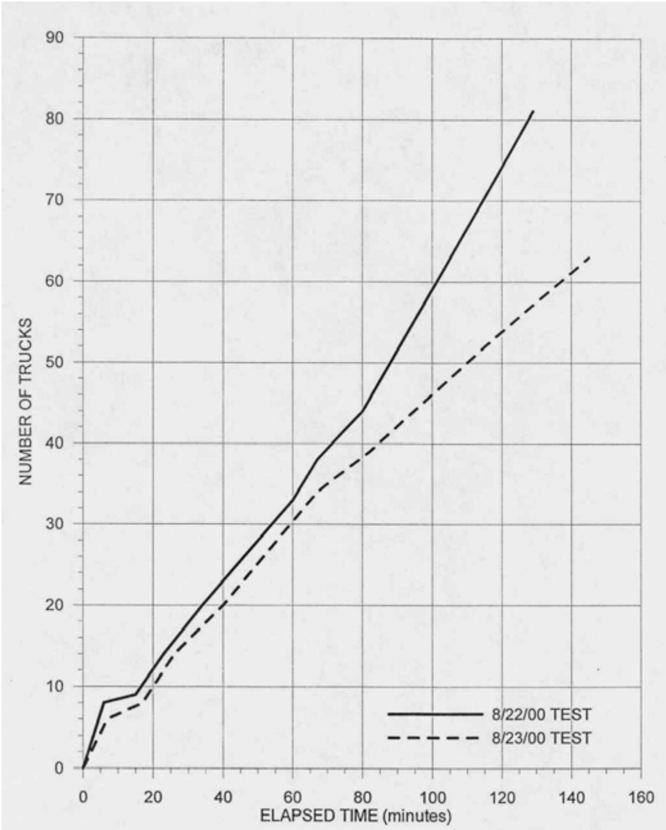

Fig. 14. Number of trucks versus time.

After at least 1 hour of truck traffic, each sample tube was carefully removed from its burrow and the volume of soil in the tube was measured. The criteria set forth in the aforementioned August 2, 2000 USFS letter stated that the maximum volume of soil collapse allowed into a burrow would be 10% of the burrow volume. This would mean that a conservative maximum volume allowed to fall into the burrow during a 1 hour test period would be 10% of the nominal minimum burrow volume or 10% x 106 cubic inches = 10.6 cubic inches of soil. It is noted that where the retrieved soil volume was very small the volume was estimated by eye as a half teaspoon, full teaspoon, full tablespoon, or one and a half tablespoons. All volumes judged to be greater than one and a half tablespoons were measured in fluid ounces by a graduated cylinder. All volumes were converted to cubic inches and are tabulated in the last column in Table A-3.

It should be noted that the test that was performed at location E-2 was invalid because a person accidentally stepped on the ground above the burrow before the sample tube was removed. The tube was removed, and the accumulated soil in the tube measured, immediately following the accidental step. The sample tube was then re-inserted into the burrow and observed with a flash light while two trucks passed and no soil was observed to collapse into the hole. Next, the same person stepped at the same place over the burrow, and the burrow again partially collapsed, resulting in a measured soil volume that was similar to that collected during the first accidental step. Also, at location B-5, there was some evidence of burrow disturbance during sampler removal and insertion due to a tight fit of the sampler tubes.

For documentation purposes, grain size distribution tests were performed on representative disturbed bag samples of soil collected from each location. The results of these tests are tabulated in Table A-5 in Appendix A. As shown in Table A-5, one representative sample of soil was collected at each of the six test sites. The test results summarized on Table A-5 show the soil to be predominately sand (76% to 87% sand size material) with small amounts of silt, clay and gravel. However, as noted in Table A-5, the abundant cobble and boulder size material was not collected; therefore, the material tested was representative of the soil matrix between the cobbles and boulders. These tests indicate relatively uniform soil conditions along the haul routes, which is consistent with the visual observations made by the project personnel.

Discussion of Results for SBKR Vibration Study

As tabulated in Table A-3, the volume of soil measured in the sample tubes after the one plus hour test period is generally in the range between 0.15 to 2 cubic inches. This results in an average of between about 4% and 17% of the allowed 10.6 cubic inches of soil fall-in. At location B-5, 5.4 cubic inches was measured in the sample tube or about 51% of the allowed volume, but as discussed above this represents a conservative measurement because it is believed that some if not all of the soil retrieved from the sample tubes resulted from hole disturbance caused by the removal of the tube from the burrow. Only at location E-2 did the soil volume exceed the allowed volume (12.6 cubic inches vs. 10.6 cubic inches of soil), but as indicated above this measurement resulted from a person stepping on the burrow before the tube was removed, and therefore, is not a valid measurement.

The range of maximum vibration measurements tabulated in Table A-4 were plotted as a function of peak particle velocity vs. frequency on log-log graphs and are shown on Fig. 15. It is noted that the highest vibration readings of between 0.1 and 0.2 ips were recorded at locations B and F, which is consistent with the observations that these locations represent the roughest road conditions coupled with the highest vehicle speeds [see Barneich (1985)]. Vibration levels measured for vehicles other than the Volvo A35 haul trucks (ie. 980C dozer, blade, and water truck) induced vibrations are also plotted on Fig. 15 and show vibration amplitudes in the range of 0.003 to 0.025 ips which are lower than the vibration levels induced by the Volvo A35 haul trucks.

All the peak particle velocities tabulated on Table A-4 are plotted vs. distance on the log-log graph shown on Fig. 16. This graph shows that on average the vibration levels measured at a distance of 10 feet from the edge of the road are 50% and 65% of those measured at a distance of 5 feet from the edge of the road for the south and north roads, respectively. This amount of vibration attenuation in the 40 to 60 Hertz frequency range is typical for the type of soil that was observed at the measurement sites (ie. sandy soils that are dry and loose to medium dense).

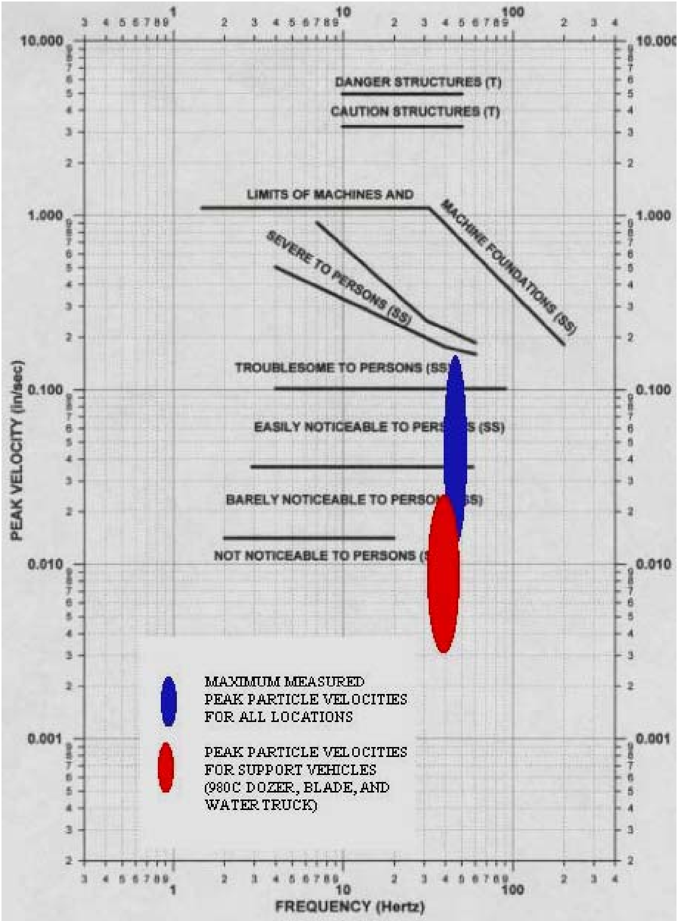

Fig. 15. Range of maximum measured peak particle velocity versus frequency.

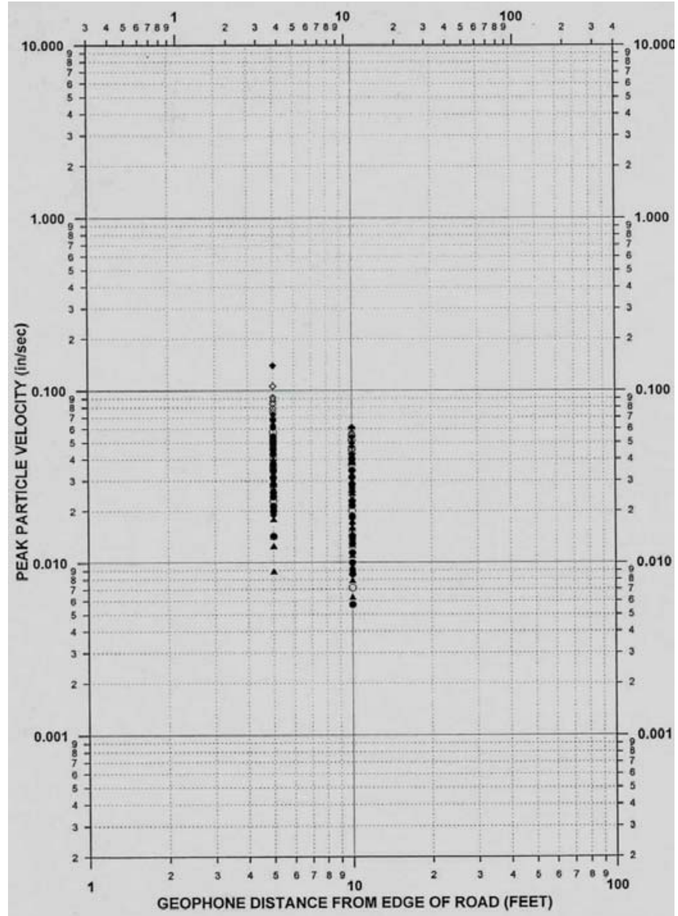

Fig. 16. Maximum peak particle velocity versus distance.

<u>Conclusions of SBKR Vibration Study</u>

On the basis of the results of the test program described in the foregoing sections, it is concluded that the vibrations induced by truck haul traffic at the south and north haul roads does not pose a problem with respect to the stability of SBKR burrows at distances of 5 to 10 feet from the edge of the road. Further, it is concluded that the vibration sensitivity tests completed met the requirements of the U.S. Department of the Interior Fish and Wildlife Service set in their August 2, 2000 letter, and that no further testing was required.

REFERENCE

Barneich, John A. [1985]. "Vehicle Induced Vibration Problems in Geotechnical Engineering", *Proceedings of Symposium on Vibration Problems in Geotechnical Engineering*, ASCE, October 22, pp. 187-202.

APPENDIX A

Table A-1. Summary of Tortoise Vibration Test Results and Tortoise Burrow Disturbance Observations

Run #	Distance to Burrow	Soil Disturbed into Burrow (approx.)	Distance to Geophone 1	Distance to Geophone 2	Geophone No. 1					Geophone No. 2				
					L (ips)	V (ips)	T (ips)	Max	~Avg. f	L (ips)	V (ips)	T (ips)	Max	~Avg. f
1A	250	0	200	250	0.0034	0.0035	0.005	0.005	45	0.003		0.003	0.003	45
1B	150	0	100	150	0.0115	0.015	0.011	0.015	50	0.005	0.0043	0.004	0.005	50
1C	100	0	50	100	0.033	0.03	0.038	0.038	50	0.009	0.0077	0.008	0.009	48
1D	75	0	25	75	0.0638	0.128	0.1	0.128	60	0.021	0.017	0.015	0.021	45
1E	45	0	5	45	0.77	0.78	0.255	0.78	60	0.0425	0.026	0.034	0.0425	55
1F	30	1 teasp	20	30	0.145	0.136	0.15	0.15	52.5	0.06	0.077	0.068	0.077	60
1G	20	1 tblsp	30	20	0.085	0.089	0.098	0.098	50	0.12	0.17	0.095	0.17	60
1H	10	0.5 cup	40	10	0.057	0.051	0.05	0.057	55	0.17	0.425	0.1	0.425	60
1I	5	1 cup	45	5	0.0425	0.027	0.034	0.0425	50	0.638	0.425	0.255	0.638	60
1J	50	0	71	47	0.026	0.034	0.034	0.034	50	0.017	0.025	0.034	0.034	55
1K	20	2 tblsp	54	17	0.053	0.038	0.051	0.053	60	0.0825	0.106	0.102	0.106	65
1L	10	2 tblsp	51	7	0.065	0.0425	0.044	0.065	70	0.17	0.81	0.26	0.81	60
2A	250	0	200	247	0.0038	0.003	0.002	0.0038	60	0.003	0.0013	0.001	0.003	65
2B	150	0	100	147	0.0136	0.0136	0.0115	0.0136	50	0.009	0.0043	0.005	0.009	60
2C	100	0	50	97	0.07	0.043	0.032	0.07	55	0.026	0.011	0.009	0.026	60
2D	75	0	25	72	0.136	0.115	0.055	0.136	50	0.025	0.013	0.009	0.025	50
2E	45	0	5	42	0.468	1.6	0.26	1.6	60	0.078	0.03	0.014	0.078	55
2F	30	0	20	27	0.18	0.21	0.11	0.21	55	0.11	0.043	0.058	0.11	60
2G	20	1 teasp	30	17	0.14	0.098	0.085	0.14	50	0.14	0.094	0.057	0.14	50
2H	10	1 teasp	40	7	0.111	0.068	0.052	0.111	55	0.17	0.387	0.28	0.387	60
2I	5	1 tblsp	45	2	0.07	0.05	0.043	0.07	55	0.68	1.53	0.29	1.53	55
2J	50	0	71	50	0.021	0.021	0.013	0.021	55	0.015	0.015	0.04	0.04	60
2K	20	0	54	20	0.034	0.023	0.023	0.034	60	0.05	0.03	0.077	0.077	60
2L	10	1 teasp	51	10	0.06	0.034	0.032	0.06	55	0.077	0.285	0.081	0.285	70

Table A-2. Summary of Tortoise Vibration Data Taken During Seismic Surveying

Shot #	Geophone No. 1					Geophone No. 2					Geophone No. 3				
	Distance (ft)	L (ips)	V (ips)	T (ips)	Max	Distance (ft)	L (ips)	V (ips)	T (ips)	Max	Distance (ft)	L (ips)	V (ips)	T (ips)	Max
1	90	0.67	0.67	0.33	0.67	150	0.2	0.2	0.07	0.2					
2	100	0.55	0.86	0.66	0.86	150	0.22	0.31	0.2	0.31					
3	30	2.1	3.2	1.2	3.2	150	0.22	0.22	0.17	0.22	150	0.2	0.16	0.09	0.2
4	80	0.7	0.6	0.35	0.7	160	0.25	0.3	0.22	0.3	60	0.6	0.6	0.5	0.5
5											50	0.98	1.4	0.43	1.4
6	100	1	0.45	0.35	1	100	0.6	0.33	0.17	0.6	58	1.9	1.6	1.6	1.9
7											50	2			2

Table A-3. Summary of SBKR Burrow Observations

LOCATION		DATE				TRUCK TRAFFIC		POST-TRUCK TRAFFIC OBSERVATIONS		
No.	Distance (ft) [1]	Sample Tube Installation		Sample Sleeve Removal		Number of Trucks	Elapsed Time (sec)	Date	Time	Volume of Soil in Sample Tube (in^3)
SOUTH HAUL ROAD - LOADED TRUCKS										
A-1	5	8/21	PM	8/22	6:22 AM	58	1 hr 45 min	8/22	9:11 AM	0.15
A-2	10	8/21	PM	8/22	6:23 AM	59	1 hr 46 min	8/22	9:12 AM	0.15
A-3	5	8/21	PM	8/22	6:20 AM	58	1 hr 44 min	8/22	9:10 AM	0.3
A-4	10	8/22	AM	8/22	6:39 AM	58	1 hr 44 min	8/22	9:10 AM	0.15
A-5	5	8/22	AM	8/22	6:30 AM	57	1 hr 43 min	8/22	9:09 AM	clean w/ beetle
A-6	10	8/22	AM	8/22	7:00 AM	56	1 hr 42 min	8/22	9:08 AM	0.15
B-1	5	8/21	PM	8/22	6:13 AM	52	1 hr 35 min	8/22	9:01 AM	0.3
B-2	10	8/21	PM	8/22	6:14 AM	53	1 hr 36 min	8/22	9:02 AM	0.3
B-3	5	8/21	PM	8/22	6:15 AM	54	1 hr 38 min	8/22	9:04 AM	0.15
B-4	10	8/21	PM	8/22	6:16 AM	55	1 hr 39 min	8/22	9:05 AM	0.3
B-5	5	8/21	PM	8/22	6:11 AM	50	1 hr 33 min	8/22	8:59 AM	5.4
B-6	10	8/21	PM	8/22	6:12 AM	50	1 hr 32 min	8/22	8:58 AM	0.3
C-1	5	8/21	PM	8/22	6:00 AM	44	1 hr 18 min	8/22	8:44 AM	0.15
C-2	10	8/21	PM	8/22	6:01 AM	44	1 hr 19 min	8/22	8:45 AM	0.3
C-3	5	8/21	PM	8/22	6:04 AM	40	1 hr 11 min	8/22	8:37 AM	clean
C-4	10	8/21	PM	8/22	6:06 AM	42	1 hr 14 min	8/22	8:40 AM	1.8
C-5	5	8/21	PM	8/22	6:05 AM	41	1 hr 12 min	8/22	8:38 AM	0.15
C-6	10	8/21	PM	8/22	6:07 AM	43	1 hr 16 min	8/22	8:42 AM	0.3
NORTH HAUL ROAD - EMPTY TRUCKS										
D-1	5	8/22	PM	8/23	6:11 AM	34	1 hr 5 min	8/23	7:59 AM	0.45
D-2	10	8/22	PM	8/23	6:12 AM	33	1 hr 4 min	8/23	7:58 AM	0.3
D-3	5	8/22	PM	8/23	6:14 AM	35	1 hr 10 min	8/23	8:04 AM	1.35
D-4	10	8/22	PM	8/23	6:13 AM	34	1 hr 6 min	8/23	8:00 AM	1.35
D-5	5	8/22	PM	8/23	6:15 AM	36	1 hr 11 min	8/23	8:05 AM	0.15
D-6	10	8/22	PM	8/23	6:17 AM	36	1 hr 12 min	8/23	8:06 AM	0.15
E-1	5	8/22	PM	8/23	6:20 AM	38	1 hr 19 min	8/23	8:13 AM	0.15
E-2	10	8/22	PM	8/23	6:21 AM	39	1 hr 21 min	8/23	8:15 AM	12.6 [2]
E-3	5	8/22	PM	8/23	6:23 AM	42	1 hr 28 min	8/23	8:22 AM	0.9
E-4	10	8/22	PM	8/23	6:22 AM	40	1 hr 24 min	8/23	8:11 AM	0.45
E-5	5	8/22	PM	8/23	6:25 AM	38	1 hr 18 min	8/23	8:12 AM	0.45
E-6	10	8/22	PM	8/23	6:24 AM	42	1 hr 29 min	8/23	8:23 AM	0.3
F-1	5	8/22	PM	8/23	6:30 AM	45	1 hr 38 min	8/23	8:32 AM	0.3
F-2	10	8/22	PM	8/23	6:31 AM	46	1 hr 39 min	8/23	8:33 AM	0.3
F-3	5	8/22	PM	8/23	6:29 AM	45	1 hr 37 min	8/23	8:31 AM	0.45
F-4	10	8/22	PM	8/23	6:29 AM	45	1 hr 36 min	8/23	8:31 AM	0.35
F-5	5	8/22	PM	8/23	6:32 AM	46	1 hr 39 min	8/23	8:33 AM	0.15
F-6	10	8/22	PM	8/23	6:28 AM	45	1 hr 36 min	8/23	8:30 AM	0.5

Notes:
[1] Distance from edge of roadway (closest tire imprint on edge of roadway)
[2] Hole stepped on by personel - reset for 2 trucks with no observed cave in. Stepped on hole and 12.6 in^3 of soil fell into tube.

Table A-4. Summary of SBKR Burrow Vibration Measurements

					PEAK PARTICLE VELOCITY (inches per second)					
				FREQUENCY	Geophone #1			Geophone #2		
		DATE		RANGE	(5 foot. offset)			(10 foot offset)		
LOCATION	SOURCE	Day	Time	(Hz)	L (ips)	V (ips)	T (ips)	L (ips)	V (ips)	T (ips)
SOUTH HAUL ROAD - LOADED TRUCKS										
A	Truck #1	8/22/00	7:26:00 AM	40 to 50	0.026	0.014	0.019	0.011	0.008	0.011
A	Truck #2	8/22/00	7:27:00 AM	40 to 50	0.021	0.018	0.019	0.014	0.008	0.015
A	Truck #3	8/22/00	7:27:30 AM	40 to 50	0.021	0.018	0.019	0.011	0.008	0.011
A	Truck #4	8/22/00	7:28:00 AM	40	0.029	0.018	0.038	0.014	0.008	0.011
A	Truck #5	8/22/00	7:28:30 AM	40 to 50	0.029	0.027	0.038	0.014	0.008	0.013
A	Truck #6	8/22/00	7:29:00 AM	40 to 50	0.026	0.027	0.038	0.014	0.010	0.017
A	Truck #7	8/22/00	7:30:00 AM	40 to 50	0.029	0.009	0.038	0.014	0.008	0.017
A	Truck #8	8/22/00	7:30:30 AM	40	0.029	0.018	0.038	0.021	0.016	0.017
A	Truck #9	8/22/00	?	40	0.026	0.022	0.047	0.014	0.011	0.017
A	Truck #10	8/22/00	?	40 to 50	0.024	0.018	0.033	0.011	0.010	0.016
A	Truck #11	8/22/00	7:45:00 AM	40 to 50	0.020	0.022	0.030	0.013	0.011	0.013
A	Truck #12	8/22/00	7:45:00 AM	40 to 50	0.026	0.013	0.032	0.011	0.013	0.017
A	Truck #13	8/22/00	7:46:30 AM	40 to 50	0.024	0.022	0.035	0.013	0.014	0.015
A	Truck #14	8/22/00	7:48:00 AM	40 to 50	0.043	0.025	0.045	0.019	0.017	0.018
LOCATION A			MIN:	40	0.020	0.009	0.019	0.011	0.008	0.011
			MAX:	50	0.043	0.027	0.047	0.021	0.017	0.018
			AVG:	44	0.027	0.019	0.033	0.014	0.011	0.015
B	Truck #20	8/22/00	8:00:30 AM	40 to 50	0.051	0.050	0.048	0.034	0.025	0.043
B	Truck #21	8/22/00	8:01:30 AM	40 to 50	0.054	0.050	0.067	0.032	0.029	0.031
B	Truck #22	8/22/00	8:02:50 AM	40 to 50	0.054	0.054	0.061	0.040	0.051	0.054
B	Truck #23	8/22/00	8:04:30 AM	40 to 60	0.031	0.029	0.042	0.029	0.022	0.027
B	Truck #24	8/22/00	8:05:50 AM	40 to 60	0.051	0.047	0.073	0.032	0.032	0.038
B	Truck #25	8/22/00	8:11:15 AM	40 to 50	0.054	0.065	0.139	0.034	0.038	0.061
B	Truck #26	8/22/00	8:12:00 AM	40 to 50	0.043	0.043	0.048	0.023	0.038	0.047
LOCATION B			MIN:	40	0.031	0.029	0.042	0.023	0.022	0.027
			MAX:	60	0.054	0.065	0.139	0.040	0.051	0.061
			AVG:	46	0.049	0.048	0.068	0.032	0.034	0.043
C1	Truck #33	8/22/00	8:26:10 AM	40 to 60	0.034	0.018	0.036	0.006	0.013	0.011
C1	Truck #34	8/22/00	8:26:55 AM	40 to 60	0.031	0.014	0.039	0.009	0.010	0.018
C1	Truck #35	8/22/00	8:29:00 AM	40 to 60	0.029	0.018	0.030	0.006	0.006	0.009
C1	Truck #36	8/22/00	8:30:15 AM	40 to 50	0.034	0.014	0.033	0.009	0.013	0.018
C1	Truck #37	8/22/00	8:32:00 AM	40 to 50	0.029	0.018	0.030	0.010	0.011	0.016
C1	Truck #38	8/22/00	8:33:00 AM	40 to 50	0.037	0.025	0.055	0.009	0.016	0.026
C2	Truck #1	8/23/00	8:57:30 AM	40 to 50	0.021	0.027	0.038	0.029	0.016	0.039
C2	Truck #2	8/23/00	9:01:55 AM	40 to 60	0.014	0.027	0.045	0.021	0.008	0.034
C2	Truck #3	8/23/00	9:02:25 AM	40 to 60	0.021	0.054	0.068	0.021	0.008	0.034
C2	Truck #4	8/23/00	9:03:00 AM	40 to 60	0.029	0.027	0.045	0.021	0.016	0.039
C2	Truck #5	8/23/00	9:04:00 AM	40 to 50	0.014	0.036	0.030	0.021	0.016	0.034
C2	Truck #6	8/23/00	9:05:50 AM	40	0.014	0.027	0.045			
LOCATION C			MIN:	40	0.014	0.014	0.030	0.006	0.006	0.009
			MAX:	60	0.037	0.054	0.068	0.029	0.016	0.039
			AVG:	47	0.026	0.025	0.041	0.015	0.012	0.025
LOCATIONS A, B, AND C			MIN:	40	0.014	0.009	0.019	0.006	0.006	0.009
			MAX:	60	0.054	0.065	0.139	0.040	0.051	0.061
			AVG:	46	0.031	0.028	0.044	0.018	0.016	0.025

Table A-4 (continued). Summary of SBKR Burrow Vibration Measurements

					PEAK PARTICLE VELOCITY (inches per second)					
				FREQUENCY	Geophone #1			Geophone #2		
		DATE		RANGE	(5 foot. offset)			(10 foot offset)		
LOCATION	SOURCE	Day	Time	(Hz)	L (ips)	V (ips)	T (ips)	L (ips)	V (ips)	T (ips)
SOUTH HAUL ROAD - SUPPORT VEHICLES										
A	Water Truck	8/22/00	7:39:30 AM	40 to 50	0.009	0.004	0.011	0.004	0.006	0.004
B	Blade	8/22/00	8:05:00 AM	20 to 40	0.014	0.022	0.024	0.014	0.019	0.025
C1	Blade	8/22/00	8:33:20 AM	40 to 50	0.010	0.005	0.012	0.004	0.005	0.007
			MIN:	20	0.009	0.004	0.011	0.004	0.005	0.004
SUPPORT VEHICLES			MAX:	50	0.014	0.022	0.024	0.014	0.019	0.025
SOUTH HAUL ROAD			AVG:	40	0.011	0.010	0.016	0.008	0.010	0.012
NORTH HAUL ROAD - EMPTY TRUCKS										
D1	Truck #1	8/22/00	9:40:00 AM	40 to 50	0.029	0.032	0.061	0.060	0.016	0.043
D1	Truck #2	8/22/00	9:43:30 AM	40 to 50	0.031	0.032	0.048	0.034	0.013	0.043
D1	Truck #3	8/22/00	9:45:30 AM	50	0.029	0.036	0.052	0.040	0.019	0.034
D1	Truck #4	8/22/00	9:46:20 AM	50 to 60	0.029	0.047	0.048	0.043	0.025	0.040
D1	Truck #5	8/22/00	9:48:00 AM	50 to 60	0.034	0.043	0.052	0.052	0.029	0.047
D1	Truck #6	8/22/00	9:52:45 AM	50 to 60	0.034	0.036	0.055	0.034	0.013	0.025
D2	Truck #2	8/23/00	6:56:00 AM	40 to 60	0.034	0.032	0.039	0.029	0.010	0.034
D2	Truck #3	8/23/00	6:57:00 AM	40 to 60	0.043	0.025	0.033	0.046	0.016	0.031
D2	Truck #4	8/23/00	6:58:30 AM	40 to 60	0.031	0.029	0.036	0.043	0.016	0.040
D2	Truck #5	8/23/00	6:59:50 AM	40 to 60	0.051	0.032	0.048	0.037	0.016	0.040
D2	Truck #6	8/23/00	7:00:20 AM	40 to 60	0.046	0.036	0.048	0.054	0.022	0.040
D2	Truck #7	8/23/00	7:01:00 AM	40 to 60	0.034	0.029	0.048	0.026	0.013	0.034
			MIN:	40	0.029	0.025	0.033	0.026	0.010	0.025
LOCATION D			MAX:	60	0.051	0.047	0.061	0.060	0.029	0.047
			AVG:	50	0.035	0.034	0.047	0.042	0.017	0.038
E1	Truck #13	8/22/00	10:10:10 AM	40 to 50	0.031	0.025	0.030	0.020	0.016	0.022
E1	Truck #14	8/22/00	10:12:45 AM	40 to 60	0.034	0.022	0.042	0.029	0.019	0.027
E1	Truck #19	8/22/00	10:23:35 AM	40 to 60	0.049	0.047	0.042	0.034	0.022	0.029
E1	Truck #20	8/22/00	10:25:15 AM	40 to 60	0.026	0.025	0.030	0.023	0.013	0.027
E1	Truck #21	8/22/00	10:28:25 AM	40 to 60	0.037	0.032	0.036	0.026	0.016	0.022
E1	Truck #22	8/22/00	10:28:55 AM	40 to 50	0.046	0.025	0.048	0.032	0.019	0.025
E1	Truck #23	8/22/00	10:29:45 AM	50 to 60	0.040	0.043	0.048	0.026	0.019	0.022
E2	Truck #11	8/23/00	?	40 to 60	--	0.032	0.042	0.026	0.035	0.027
E2	Truck #12	8/23/00	?	40 to 60	--	0.043	0.055	0.023	0.035	0.025
E2	Truck #14	8/23/00	7:22:15 AM	40 to 50	0.026	0.039	0.067	0.029	0.029	0.022
E2	Truck #15	8/23/00	?	40 to 50	0.020	0.029	0.052	0.023	0.025	0.027
E2	Truck #16	8/23/00	7:25:50 AM	40 to 50	0.014	0.022	0.027	0.023	0.022	0.022
			MIN:	40	0.014	0.022	0.027	0.020	0.013	0.022
LOCATION E			MAX:	60	0.049	0.047	0.067	0.034	0.035	0.029
			AVG:	48	0.032	0.032	0.043	0.026	0.023	0.025
F1	Truck #27	8/22/00	10:37:50 AM	40 to 50	0.029	0.036	0.045	0.023	0.022	0.025
F1	Truck #28	8/22/00	10:39:35 AM	40 to 60	0.023	0.025	0.045	0.020	0.019	0.027
F1	Truck #29	8/22/00	10:43:00 AM	40 to 60	0.026	0.032	0.048	0.026	0.025	0.027
F1	Truck #30	8/22/00	10:44:25 AM	40 to 50	0.034	0.047	0.067	0.032	0.032	0.029
F1	Truck #31	8/22/00	10:45:30 AM	40 to 50	0.026	0.032	0.048	0.023	0.025	0.027
F1	Truck #32	8/22/00	10:46:55 AM	50	0.029	0.043	0.055	0.029	0.025	0.027
F1	Truck #33	8/22/00	10:48:05 AM	40 to 50	0.029	0.043	0.079	0.026	0.032	0.040
F2	Truck #21	8/23/00	7:35:40 AM	40 to 50	0.043	0.065	0.079	0.020	0.029	0.034

Table A-4 (continued). Summary of SBKR Burrow Vibration Measurements

LOCATION	SOURCE	DATE Day	DATE Time	FREQUENCY RANGE (Hz)	PEAK PARTICLE VELOCITY (inches per second) Geophone #1 (5 foot. offset) L (ips)	V (ips)	T (ips)	Geophone #2 (10 foot offset) L (ips)	V (ips)	T (ips)
F2	Truck #22	8/23/00	7:37:40 AM	40 to 50	0.043	0.072	0.083	0.021	0.024	0.051
F2	Truck #23	8/23/00	7:41:10 AM	40 to 60	0.057	0.090	0.076	0.021	0.032	0.045
F2	Truck #24	8/23/00	7:42:35 AM	40 to 50	0.036	0.027	0.053	0.007	0.016	0.045
F2	Truck #25	8/23/00	7:43:20 AM	40 to 60	0.043	0.072	0.091	0.014	0.032	0.056
F2	Truck #26	8/23/00	7:45:15 AM	40 to 50	0.050	0.054	0.106	0.021	0.040	0.056
LOCATION F			MIN:	40	0.023	0.025	0.045	0.007	0.016	0.025
			MAX:	60	0.057	0.090	0.106	0.032	0.040	0.056
			AVG:	47	0.036	0.049	0.067	0.022	0.027	0.038
LOCATION D, E, AND F			MIN:	40	0.014	0.022	0.027	0.007	0.010	0.022
			MAX:	60	0.057	0.090	0.106	0.060	0.040	0.056
			AVG:	48	0.035	0.039	0.053	0.030	0.022	0.034
NORTH HAUL ROAD - SUPPORT VEHICLES										
D1	980C Dozer	8/22/00	?	40 to 60	0.009	0.007	0.009	0.003	0.006	0.007
E2	Blade	8/23/00	?	40	--	0.007	0.012	0.006	0.006	0.009
E2	980C Dozer	8/23/00	?	40 to 50	0.009	0.014	0.015	0.009	0.006	0.016
E2	Water Truck	8/23/00	7:25:45 AM	40 to 60	0.006	0.004	0.015	0.009	0.016	0.018
F1	Water Truck	8/22/00	10:39:30 AM	40	0.009	0.007	0.012	0.003	0.006	0.009
F1	Blade	8/22/00	10:46:00 AM	40 to 50	0.011	0.014	0.018	0.011	0.013	0.013
SUPPORT VEHICLES NORTH HAUL ROAD			MIN:	40	0.006	0.004	0.009	0.003	0.006	0.007
			MAX:	60	0.011	0.014	0.018	0.011	0.016	0.018
			AVG:	46	0.009	0.009	0.014	0.007	0.009	0.012
ALL SUPPORT VEHICLES			MIN:	20	0.006	0.004	0.009	0.003	0.005	0.004
			MAX:	60	0.014	0.022	0.024	0.014	0.019	0.025
			AVG:	44	0.009	0.009	0.014	0.007	0.009	0.012

Table A-5. Summary of Gradation Tests for SBKR Vibration Study

LOCATION Site	Burrow No.	PERCENTAGE [1] Gravel	Sand	Silt	Clay	UNIFIED CLASSIFICATION Symbol	Description [2]
A	1	7.3	82.1	7.7	2.9	SP-SM	Silty to Clean Sand with trace Gravel
B	3	1.5	86.7	8.6	3.2	SP-SM	Silty to Clean Sand with trace Gravel
C	5	4.2	84	1.4	10.4	SP	Clean Sand with trace of Gravel and Clay
D	2	3.1	77.3	15.1	4.5	SM	Silty Sand with trace Gravel
E	3	1.8	76.1	5.7	16.4	SC-SM	Silty to Clayey Sand with trace Gravel
F	2	1.7	78.5	5.7	14.1	SC-SM	Silty to Clayey Sand with trace Gravel

Notes:

[1] By weight - Gravel: >0.25 in.
Sand: 0.25 in. to 0.005 in.
Silt: 0.005 in. to 0.0002 in.
Clay: <0.0002 in.

[2] Samples were biased due to not including greater than 3 in. material; therefore, gravel sizes and larger are underestimated.