VIBRATION MONITORING

AND

CONTROL OF BLASTING

ASSOCIATED WITH THE RELOCATION

OF HIGHWAY H,

GREEN COUNTY, MISSOURI.

Submitted to the Missouri Highway and Transportation Comission

by

Mark Kirkbride, Dr. Paul Worsey and Dr. Gerald Rupert

of the

Rock Mechanics and Explosives Research Center

University of Missouri-Rolla

Dr. Paul Worsey, Principal Investigator

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INTRODUCTION

General Statement

This project was originally scheduled for 1994. However, because of the construction delay of the Highway H realignment, it was postponed until the summer of 1995. The contract period was from 1 May 95 to 30 Sept. 95. The contract was bid for two different time frames. One was a five week period of field work and summary report compilation and the alternative was a ten week period of field work and summary report compilation. For those unfamiliar with blasting terminology, a brief tutorial is included as Appendix A in which terms are defined.

Contract Responsibilities

The six tasks to be accomplished as specified by this contract are those in the University of Missouri-Rolla proposal The Vibration Monitoring and Control of Blasting Associated With The Relocation of Highway H Green County, Missouri dated April 4, 1993. These are: 1) participate in a pre-excavation liaison with Highway Commission personnel and the contractor 2) recalibrate instruments currently in boreholes 3) monitor all production and test blasts and process the associated vibration data 4) advise Highway Commission personnel of acceptable blasting limits and site blasting control 5) remove all equipment after blasting completion and 6) and submit a summary report.

The objective of these tasks was to prevent or minimize any damage to Crystal Cave resulting from the realignment of Highway H. This was to be done with the cooperation of Journagan Construction Company, the prime contractor for the realignment; on site

Missouri Highway and Transportation Department personnel; and Mr. and Mrs. Richardson, the owners and operators of the cave. Monitoring and recommended procedures were to be such that minimal interference with construction or changes in standard blasting procedures would occur. Seismographs would be placed in the cave and surrounding property to gather preliminary data of blasting located at the furthest end of the project area. This initial data would then be used to predict vibration levels associated with given pounds of explosives per delay at a known distance. The blaster for Journagan was then to be advised of the maximum pounds of explosives per delay for the location in which he was preparing to shoot. As blasting proceeded towards the cave, the vibration predictions were to be continually refined as more information was acquired from the previous blasts.

Highway H Realignment Project

The Highway H realignment project was implemented to provide motorists with a greater line of sight on Highway H between the Highway KK junction to just north of the Highway WW junction. To prepare the new roadbed, blasting would be conducted as near as 400 feet from Crystal Cave and 640 feet from its public portions. In order to prevent damage to the cave, a cooperative group effort would be necessary. This group would consist of on site personnel of the Missouri Highway and Transportation Commission and the University of Missouri-Rolla in addition to blasting personnel of Journagan Construction Co.. Mr. and Mrs. Richardson, owners and operators of the cave, were to be consulted and informed regarding blasting schedules in order to minimize interference with the scheduling and conduction of commercial tours. As an extra safety precaution, tours were not conducted during blasting.

Crystal Cave

Crystal Cave is a commercial cave located 5 miles north of Interstate I-44 at the intersection of Highways H and KK. The cave is owned and operated by Lloyd and Edith Richardson and has been in Mrs. Richardson's (the Mann) family since 1893. The cave has several unique structures. Concern existed that these would be damaged as a result of the construction blasting. In particular was the hanging balcony. This feature is a perforated chert layer suspended from the roof by a column, the underlying clay layer having been eroded away. Fragile helicites occur in one room. These are relatively rare forms of stalactites which grow in spiral or angular directions rather than in a vertical one. Soda straw stalactites are also in abundance.

PREVIOUS RESEARCH

Extensive research has been conducted regarding the effect of blast vibrations on surface features. However, for this project the effect on underground cave structures was of major concern and interest. Prior to the issuance of this contract, the University conducted a preliminary rock excavation study and blasting program at Crystal Cave. Major objectives were to determine whether blasting could be conducted without damaging the cave and to develop scaling laws which related peak particle velocities to scaled distances with the restriction that no damage to the cave occurred. Thus, at the initiation of future production blasting the resulting data could be used to estimate charge weights per delay given the blast to cave distance. The contract report submitted to the Missouri Highway and Transportation Commission is Crystal Cave Rock Excavation Study, Job No. J8S0331, December 1992[1] . As a result of the investigation and the later paper Results of Test Blasting at Kartchner Caverns[2] , discovered at the beginning of this contract, initial peak particle velocities of the blasting program were limited to 0.3 in/s. which is one half that recommended for Kartchner Caverns.

EXPERIMENTAL METHOD

Pre-excavation Liaison

Prior to the beginning of the Highway H realignment construction, a pre-excavation conference was held in Springfield, Missouri and at the Missouri Highway and Transportation Commission Building. This was attended by Missouri Highway and Transportation Commission personnel, representatives of Journagan Construction Company, the prime contractor, and Dr. Paul Worsey of the Rock Mechanics and Explosives Research Center (RMERC), University of Missouri-Rolla. The liaison's purposes were to define the roles of each party, to emphasize the need for communications throughout the duration of the project, and to successfully and efficiently complete the blasting program. This was to be accomplished with least interference with the operation of Crystal Cave and without inflicting damage to the same. This placed a conservative restriction on the peak particle velocities from blasting. It was further recommended that blasting begin at the northern extremity (maximum distance from the cave) and that charge weights per delay not exceed those used in the initial research. As blasting continued towards the cave, the additional data would be continually analyzed and the peak particle velocity vs scaled distance curves refined because of the different types of blasting. Recommendations for changing explosive weights and/or patterns would be made to the on site highway engineer and the contractor as necessary.

Removal and Recalibration of Borehole Instruments

Five three component geophone clusters were installed in drill holes for Job No. J8S0331 completed in December 1992. If possible, these were to be removed, recalibrated, and again installed in the same holes. Four visits to Crystal Cave were conducted for these purposes. All attempts to hoist the clusters by their data transmission cables were unsuccessful even though a winch was eventually employed . It was apparent that rock fragments resulting from hole collapse had wedged the instruments. A high pressure (20000 psi) water wand was utilized in an attempt to dislodge the fragments. This too was unsuccessful and further efforts of removal were terminated. Although the instruments and their locations were not necessary for the monitoring of the cave itself, they would provide useful supplemental data. One cluster was destroyed during the highway realignment, and the remainder were abandoned. A request was made by RMERC to the Missouri Highway and Transportation Commission to fill and cap the boreholes at the completion of the project.

On Site Training and Blasting Control

Training

Journagan personnel routinely used an electric detonating system but because of the limited number of shot delays a change to a non-electric system was made early in the project. This permitted the detonation of larger shot sizes. Thus, the blasting would consist of one large detonation at the end of the workday rather than several smaller ones throughout the day. This eliminated the need to interrupt construction and minimized interference with Crystal Cave tours. RMERC personnel assisted the Journagan Construction Co. blaster in a change to this new initiation system by providing training and field assistance. Mr. Jon Drake was the head blaster for the Journagan Construction Co. for the entire project and was most cooperative and receptive to suggestions.

Blasting Control

Several blast designs were suggested by the University personnel and implemented by the blaster for Journagan. The objective was to find a blast pattern that would help reduce vibrations in Crystal Cave while improving the effects on the blasts for the construction of Highway H. Mr. Jon Drake worked closely with University personnel in assessing the performance of the different shot designs from the construction aspect. Although vibration reduction was of primary importance, construction needs could not be dismissed. Unfortunately, those designs best for construction needs resulted in the highest vibrations. However a compromise was chosen which minimized the vibrations at Crystal Cave while still maintaining blasting performance at an acceptable level.

To provide close monitoring and assure control of blasting operations, RMERC personnel were present and assisted in loading and hooking in the majority of the shots. This was done to both confirm correct procedures were used and to assure that the correct blasting data was reported for different periods.

Blasting Parameters

The blasting was performed by Journagen Construction under the direct control and supervision of John Drake (Blaster in charge). The initial initiating system was millisecond (ms) period electric caps which were used only on the far north end of the contract no nearer than approximately 2,000 feet from the cave (Highway W and North). This was changed to a non-electric system for the remainder of the contract. This utilized EZ det nonelectric caps with 25 ms surface and 350 ms down the hole delays (Figure 1) and 42 ms surface row to row delays (Figure 2). Drill Holes of 3.0 inch diameter were drilled by crawler rigs up to approximately 25 ft. in depth. The holes were primed using single cartridges of Tovex Trenchrite 5 (Figure 3). Dry holes were then loaded with ETI ANFO P prill (Figure 4) and wet holes with ICI Nitropel, a TNT prill (Figure 5). Each hole was stemmed with drill cuttings. The holes were normally drilled on a rectangular pattern of 7 ft. spacing and 5 ft. burden and fired in a V pattern. Examples of shots are given in Figure 6 and Figure 7. Occasionally flyrock was experienced (Figure 8). A typical muck pile post blast is shown in Figure 9.

The final excavation walls were pre-split using 3.0 inch holes on 3.5 ft. spacing and loaded with ETI Trimrite explosive. The entire pre-splitting was completed before rock excavation commenced south of the S bend in the original road. Due to the higher than normal blast vibrations associated with pre-splitting at distances less than 2,000 ft from the cave, pre-split delays were used in each panel to reduce the pounds per delay to an acceptable level. Close to the cave each pre-split hole was fired on a separate delay period.

Figure 1: EZ det initiator hookup at hole showing surface delay.

Figure 2: Primadet 42 ms surface delay.

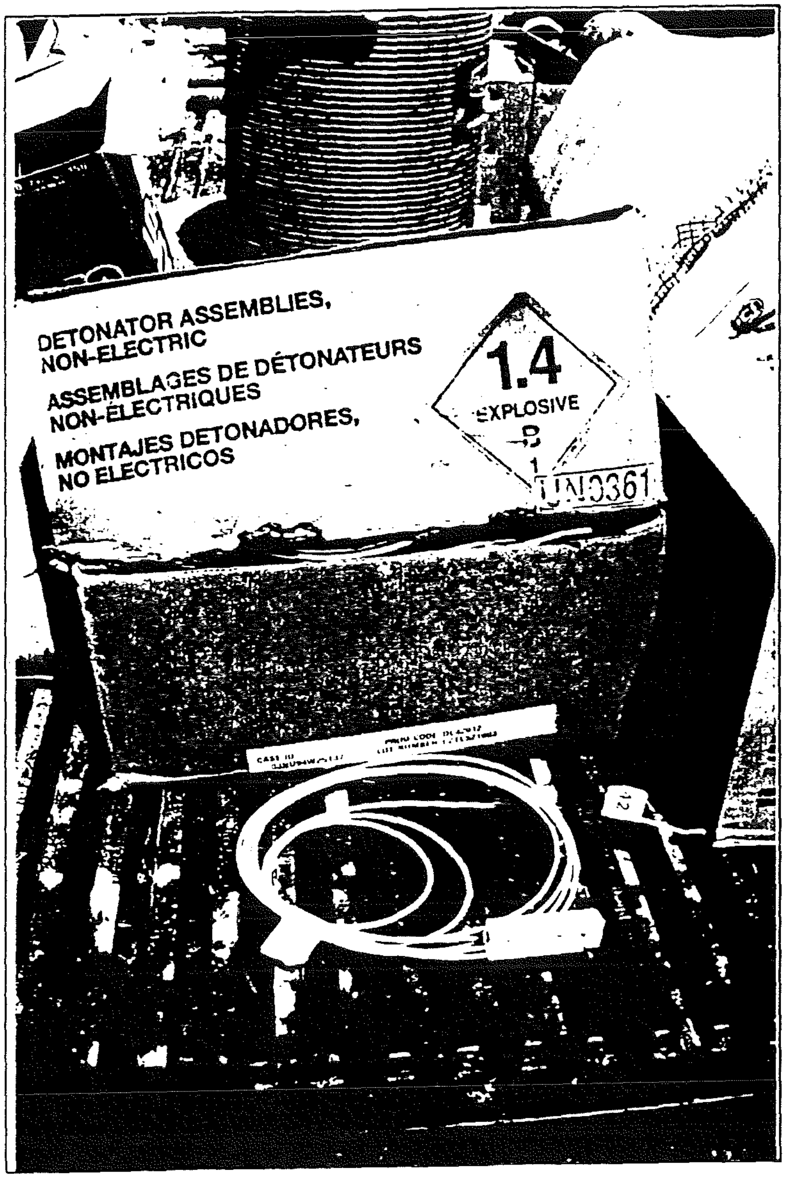

Figure 3: Tovex Trenchrite explosive cartridge

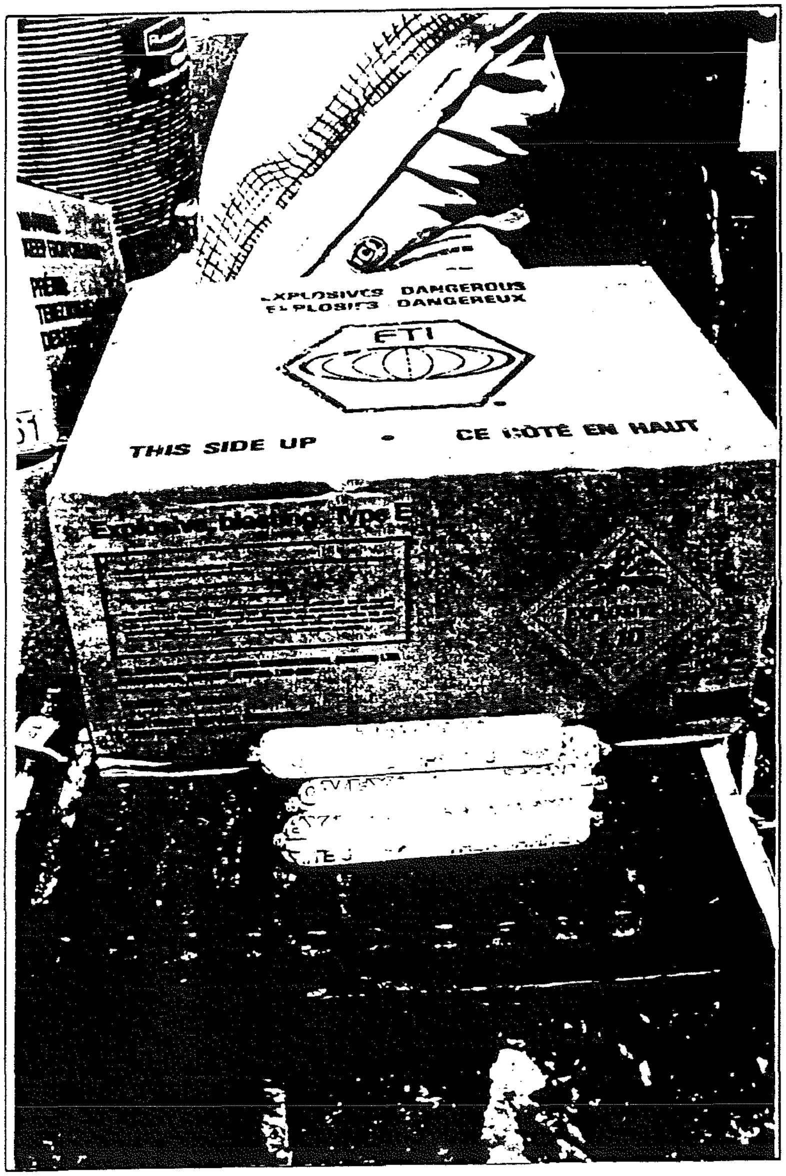

Figure 4: ANFO P blasting agent

Figure 5: Nitropel prill

Figure 6: Typical shot across and approximately 1000 feet from cave.

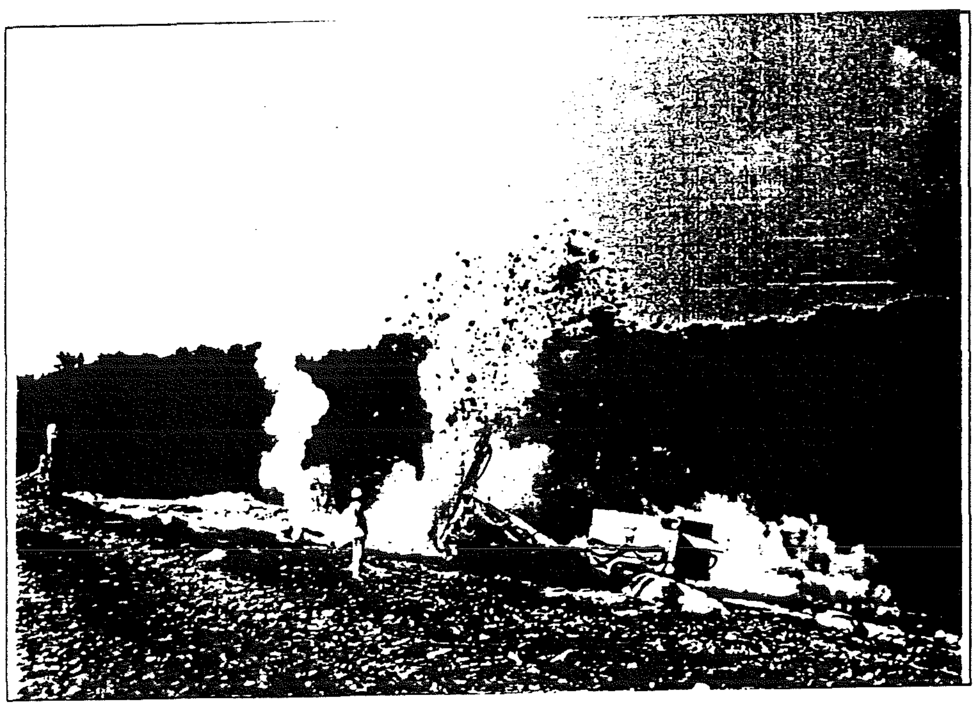

Figure 7: Shot approximately 700 feet from show portion of cave.

Figure 8: Flyrock getting away on a shot.

Figure 9: Typical shot muck pile against Williamsons' property line. Pre-split at perimeter just showing.

Instrumentation

In Crystal cave itself, six interior instrument stations were used throughout the project. In addition two temporary positions, one on the surface and one underground, were sometimes utilized.. The six primary locations were chosen on the basis of the formation fragility and minimal interference with cave tours. Additionally, the six stations were chosen so as to represent the major portions of the cave open to the public. Locations are as indicated on the attached map of the cave (see Figure 10) and their descriptions are given further in this section. In these descriptions relative directions, such as left and right, are with reference to traveling away from the entrance. At some locations different units were used during the project. This was because of instrument malfunctions mainly due to the damp environment and the time required for the repair of the unit.

For the previous research, Oyo Geospace Corporation HS-1 three component geophones were mounted down holes and their data transferred to a central computer via cables. Triggering was accomplished by manually activating the recording system upon receipt of a voice signal prior to blasting. This proved satisfactory for the small number of controlled blasts, and the resulting data enabled scaling laws to be developed. However, for the current project the monitoring of various portions of Crystal Cave was both a necessity and a priority. Consequently, the seismographs would be mounted on underground surfaces rather than in boreholes. The use of cables and the manual triggering , while feasible, would be an inconvenience.

In January of 1993, the RMERC acquired two Larcor mini digital seismographs, model MS-2D2G, from White Industrial Seismology, Inc[3]. These are the next generation equivalents of the six MS-1D instruments already owned by the center. The introduction of the former instruments on the market in late 1992, after the end of the Crystal Cave rock excavation study, signified a new generation in instrumentation. Thus it was decided to utilize these and the MS-1D instruments rather than the Oyo ones for the following reasons: 1) the geophones, recording hardware, and power source are contained in a small unit of approximately 3.5 pounds and of size 7.5 in X 4.5 in X 2,5 in; 2) triggering is automatic upon detection of a user selected level; 3) each unit is capable of storing 341 events in solid state memory; 4) summary information can be viewed on the LCD instrument display; and 5) full waveform data can be obtained by downloading to a PC via a RS232 serial port. The older MS-1D units (016-021) have internal geophones and record to the nearest 0.01 in/s while the newer MS-2DS units (491 and 492) have external geophones and record to the nearest 0.005 in/s. Because of the features of both instrument types, a triggering and data cable system from the construction site into the cave was unnecessary.

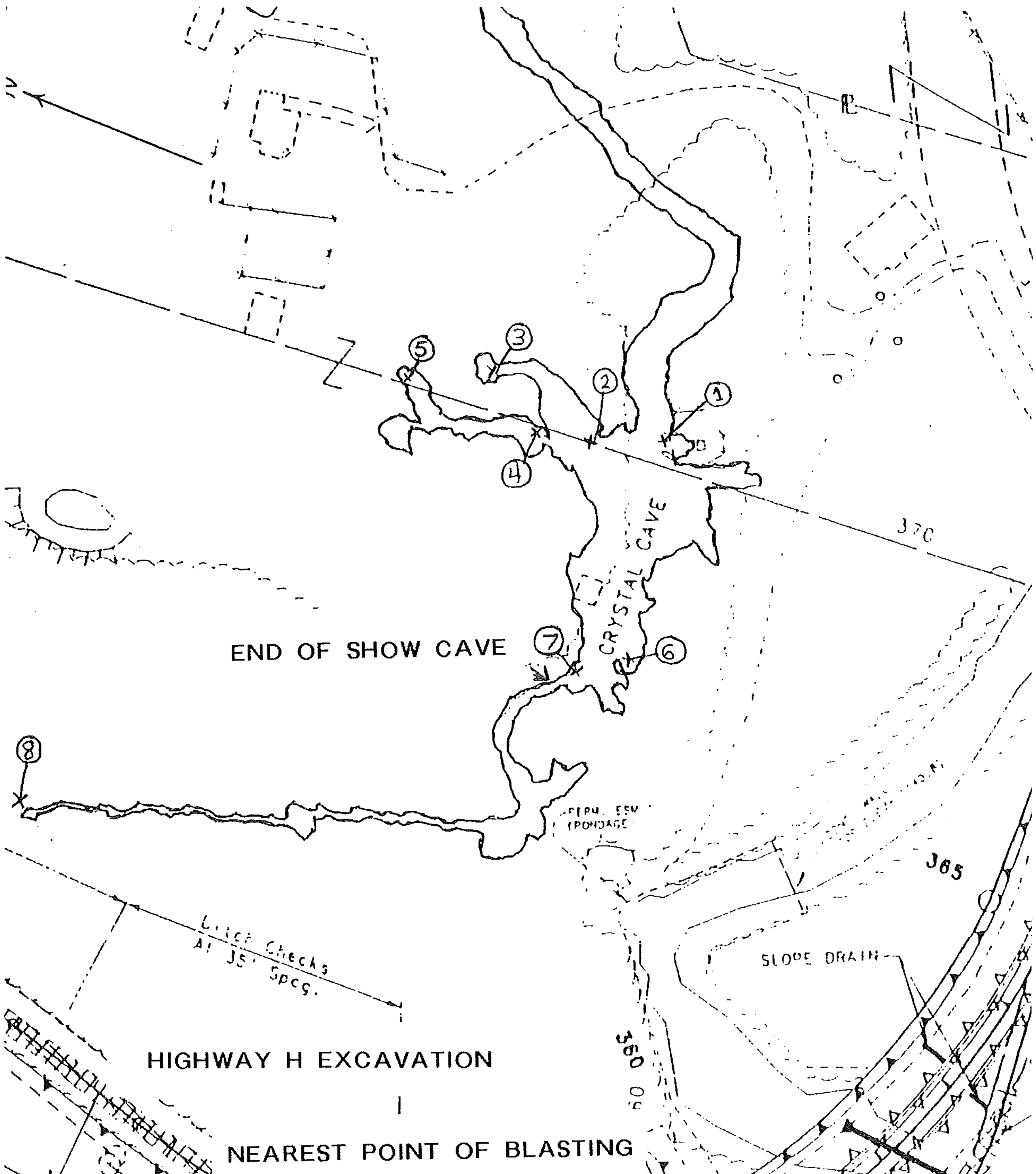

Figure 10: Map of cave illustrating instrument stations.

Mounting Procedures:

All the seismographs installed were three component units and record vertical, tangential, and radial particle velocity data.. Because of the difficulties of aligning the instruments to face all of the individual blasts while underground; partially because the line of blasting was moving in an arc around the cave; and also because there were as many as four blasts per day and at different locations, the instruments were aligned with the digital display facing north-south. Hence, the radial in this report is north-south and tangential is east-west for all events.

The MS-1D units (Figure 11) and the geophones of the MS-2D2G instruments (Figure 15) were mounted on metal plates for additional stability and weighted with sandbags to both improve coupling to the ground and to minimize extraneous vibrations. The seismic trigger level was set to 0.03 in/s on all instruments for most of the project. Two units were set to trigger at 0.05 in/s during the first few weeks of the project, but by 1 June '95 these were reduced to 0.03 in/s. The acoustic triggers were not used not only because overpressure inside the cave was minimal but also because of the possibility of accidental activation by tour groups.

Each seismograph contained a 6 volt rechargeable battery which permitted the unit to operate for approximately nine days. However, each unit was also connected to an external 12 volt lawn tractor battery which served as the primary DC power source. See later Figures. Power was conserved by instrument timers which deactivated the units during the night when excavation operations were inactive. The use of dual power sources permitted the seismographs to be left undisturbed for the duration of the project and minimized the possibility of instrument power failure.

Instrument Stations

Entrance Room

Instrument No. 21 was located in the first chamber of the cave where it remained throughout the project. The location was down the first flight of stairs and approximately 15 feet to the right of the railing. Mounting was on a rock ledge with a distance of about 25 ft to the roof. See Figure 11. Station conditions were dry. Instrument No. 21 was positioned at this location throughout the entire project. This is location #1 on Figure 10.

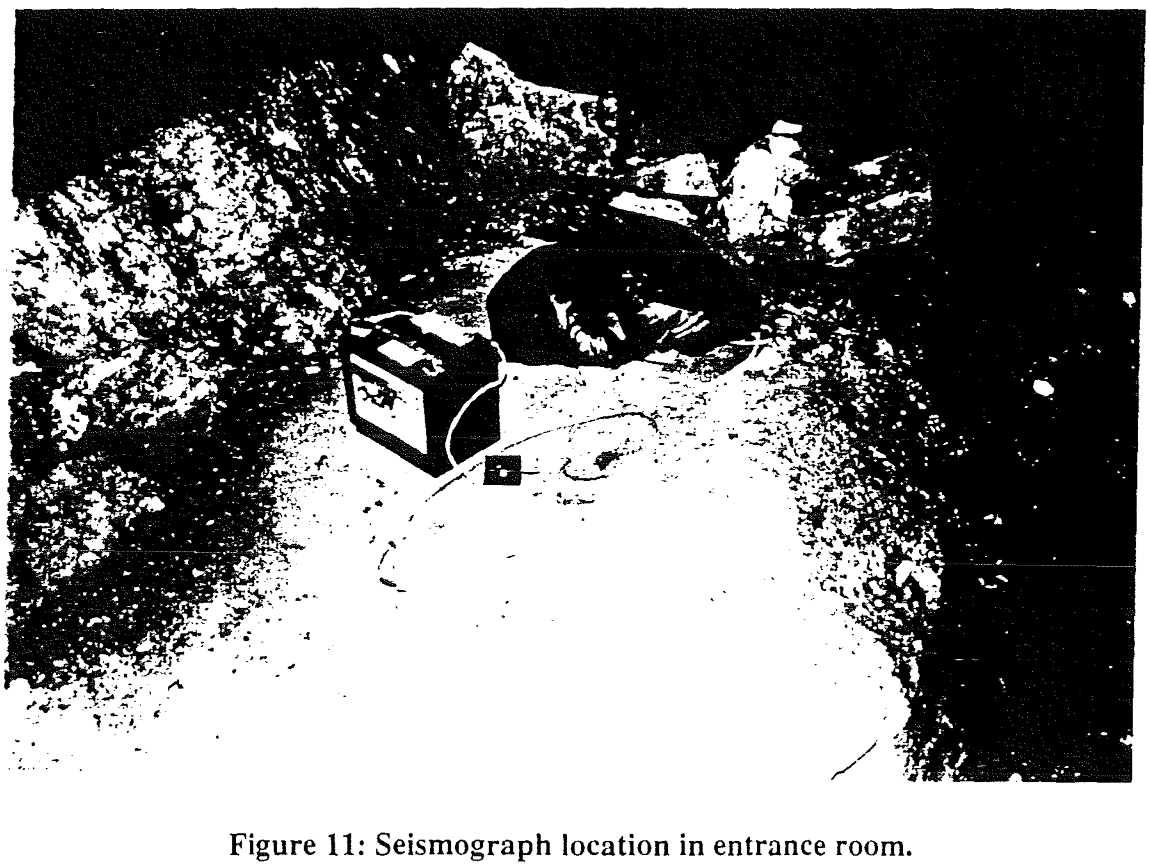

Figure 11: Seismograph location in entrance room.

Hanging Balcony

Instrument No. 16 was located immediately behind the hanging balcony. The station is approximately 2 ft to the right of the railing at the top of the stairs and is in front of a large stalagmite and a column. The mounting was on a chat and clay mixture. See Figure 12. Station conditions were wet and the distance to the roof is about 4 feet. The location is No. 2 on Figure 10.

Figure 12: Seismograph location on Hanging Balcony.

Indian Sleeping Chamber

The Indian sleeping chamber (INS in Appendices C and D) is north of the Cathedral Room and is not part of the standard tour. Clay steps lead into the room. The instrument location was approximately 5 ft from the top of these steps. The mounting was on rock about 4.5 ft to the ceiling. See Figure 13. Conditions were dry. Instrument No. 19 was positioned at this location for the periods 11 May 95 to 12 May 95 and 21 June 95 to 17 July 95. Instrument No. 17 was substituted for the periods 13 May 95 - 20 June 95 and 18 July 95 to the end of the project. A third Instrument, No. 18, was positioned at this location during the period 17 June 95 to 22 June 95. This instrument location is No. 3 on Figure 10.

Figure 13: Seismograph location in Indian Sleeping Chamber

Jacob's Room

The instrument location was approximately 12 ft to the right of the railing immediately after entering Jacob's room. The mounting was on a rock slab resting on a layer of clay and having a distance of about 6 ft to the ceiling. See Figure 14. Station conditions were dry. Instrument No. 492 was positioned at this location during the period 11 May 95 to 17 July 95 and Instrument No.18 was positioned at this location from 18 July 95 to the end of project. This is location No. 4 on Figure 10.

Figure 14: Seismograph location in Jacob's Room.

Helectite Room

The Helectite room is in actuality the rear portion of the chamber named the Chimes Room and is not part of the standard tour. This area is closed to the public because of the fragile nature and rarity of some of its Helectite formations. The instrument location was approximately 15 ft beyond a rope barrier at the end of the chat path and on the right side. The mounting was on a Gour Pool formation with a distance of about 7 ft to the ceiling. See Figure 15. Conditions were wet. Instrument No. 491 was positioned at this location during the dates 11 May 95 to 30 July 95 and was replaced with instrument No. 492 during the time 31 July 95 to the end of project. This is location No. 5 on Figure 10.

Figure 15: Seismograph location in Helectite Room.

MS-2D2G Seismograph with external geophone. Geophone under black sand bag.

Also illustrating external power source - 12 volt lead acid battery.

Lloyd's Room

The instrument was located approximately 15 ft beyond the end of the chat walk and on the right side near a column broken at the top end. The mounting was on clay with about 5 feet to the ceiling. See Figure 16. Conditions were damp. Instrument No. 20 was in place for the entire project. This location is designated No. 6 on Figure 10.

Figure 16: Seismograph location in Lloyd's Room.

Entrance to Lake Room:

The instrument location was on a protruding rock ledge at the end of the chat path near the entrance to the lake room. The mounting was on rock with about 8 ft to the ceiling. Conditions were dry. Instrument No. 18 was positioned at this location during the dates

16 June 95 to 17 June 95. This was a temporary location established to compare and verify values recorded in the nearby Lloyd's Room. After three blasts with similar findings at both locations instrument No. 18 was removed and used to replace the malfunctioning instrument No. 17. This is location No. 7 on Figure 10.

Exterior

This was a temporary station. located on a rock outcrop which was assumed to extend into the cave. It is located in a draw approximately half way between the Richardson's pond and the original Highway H. It was also approximately half-way between the cave and blasting at that time the station was in use. It provided preliminary data that was useful in predicting vibrations as cave to blasting distances decreased. The mounting was on a rock outcrop on the surface. Instrument No. 18 was mounted on the outcrop at this location during the dates 1 June 95 to 15 June 95. This is location No. 8 on Figure 10.

Data Acquisition and Processing

After each shot was completed, the cave was entered and the associated summary data from each seismograph transferred to a log sheet. Figure 17. This data consisted of the date, time, event number, peak component velocity, and vector sum. The collection of this data permitted the daily upgrading of the peak particle velocity vs scaled distance plot. These data are summarized in Appendix C. Full waveform data were obtained by downloading weekly to a laptop PC (Figure 18) via a RS232 serial port[4]. Copies are in Appendix E.

Blasting statistics and seismograph data were compiled on a spreadsheet, and a peak particle velocity vs scaled distance graph constructed. Figure 19. This permitted the Journagan blaster to estimate the number of pounds of explosives per delay that could safely be used at a given location. The graph was constantly upgraded as additional blast data became available. Full waveform data was analyzed by means of Seismograph Data Analysis for Windows version 2.0[5]. This produced a full waveform trace and graphs based on criteria of both the Office of Surface Mining, and the United States Bureau of Mines, and the frequency amplitude spectra of the recorded waveforms. The later identified the dominant frequencies recorded at each station. These are functions of both the explosive waveform and the recording location. The spectra enable shot delay times to be calculated so as to minimize unwanted frequencies. Whenever a change in delay times was suggested, the blaster for Journagan was so advised. Although some processing of the data was conducted on site, it was also sent to the Rock Mechanics and Explosives Research Center, University of Missouri-Rolla for additional detailed analyses. Additional information such as the blast performance, from a construction aspect, was also provided by University personnel on site. After each blast, consultations were held between Jon Drake and University personnel to evaluate shot performance and the details of the blast pattern including layout, timing, and pounds per delay. These statistics were recorded. Discussions related to improvement of shot design were conducted. When agreed to be mutually feasible and beneficial to excavation and cave vibration reduction, they were implemented.

All blasting was conducted between 11 May 95 and 1 Aug. 95 except for one small blast conducted at the northern end at the pipeline crossover the week of 4-8 September, 1995. Although for the last blast all the seismographs were active, none were triggered. All instruments remained in Crystal Cave from 11 May 95 to 19 Sept. 95 and University personnel were on site for all blasts except those whose scaled distance was considered great enough to result in negligible, peak particle velocity values.

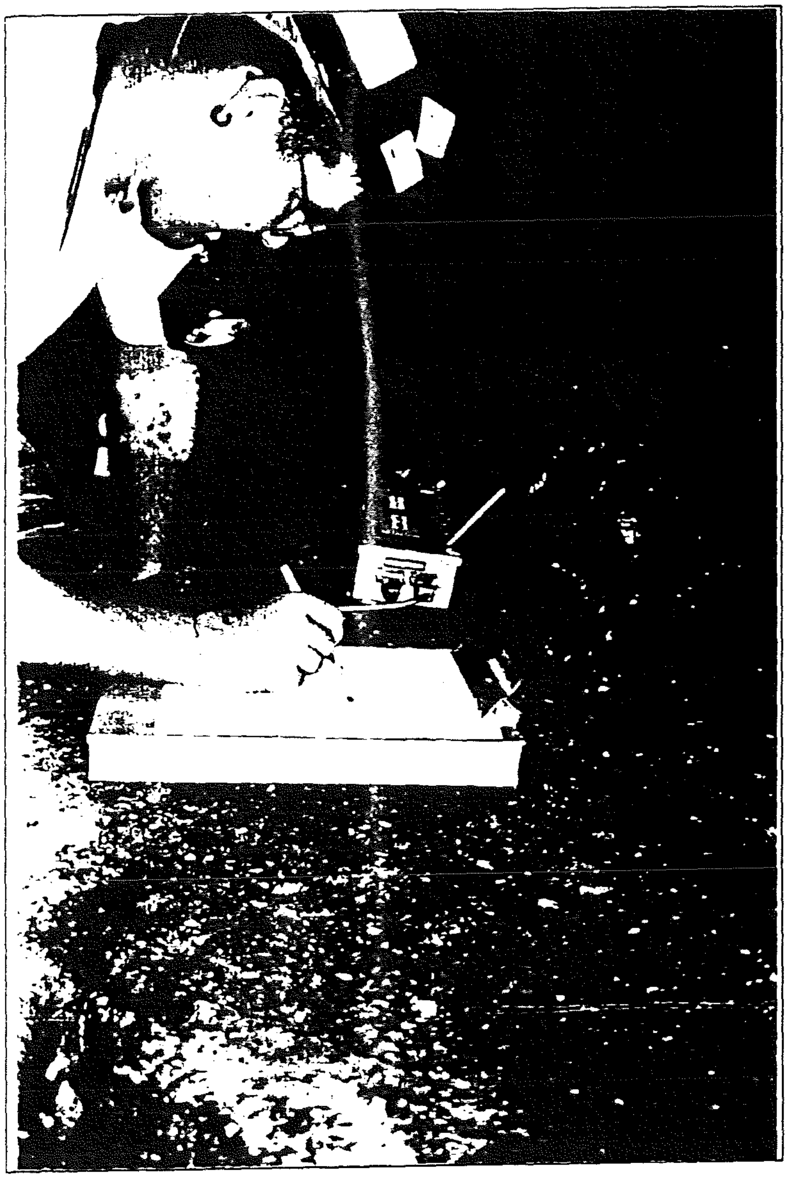

Figure 17: Taking blast readings after a blast.

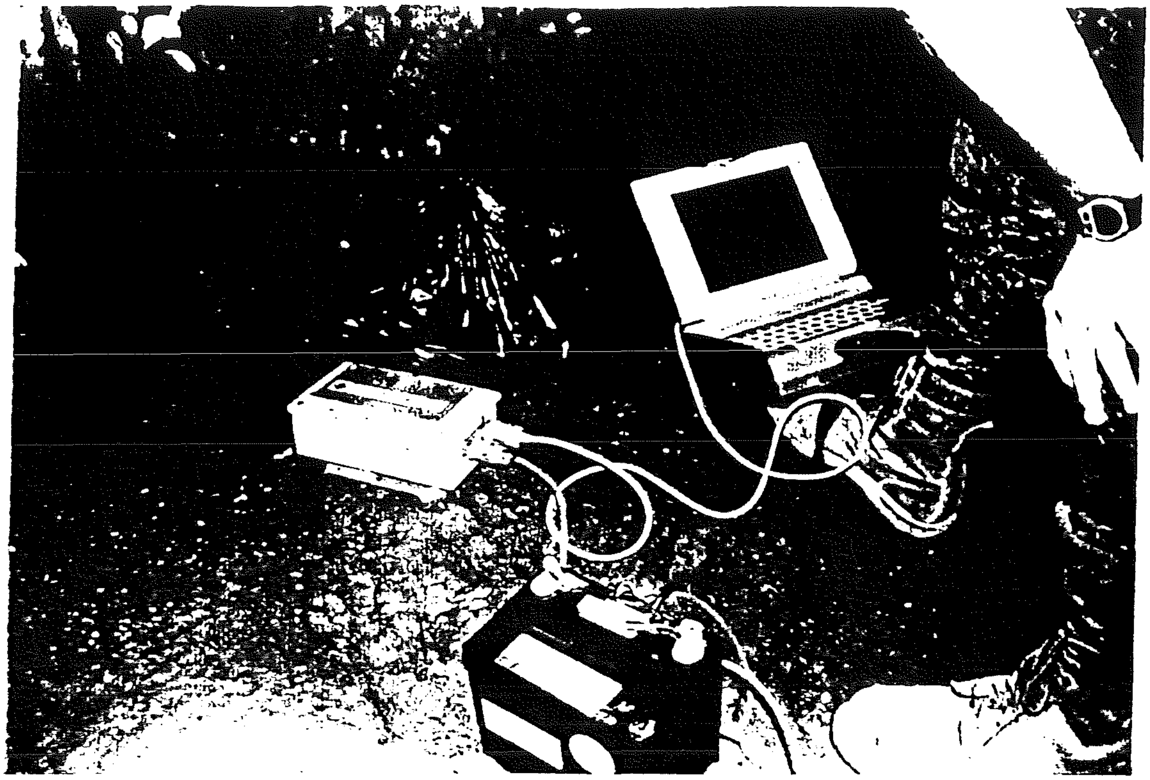

Figure 18: Weekly download of seismograph waveform data to laptop PC.

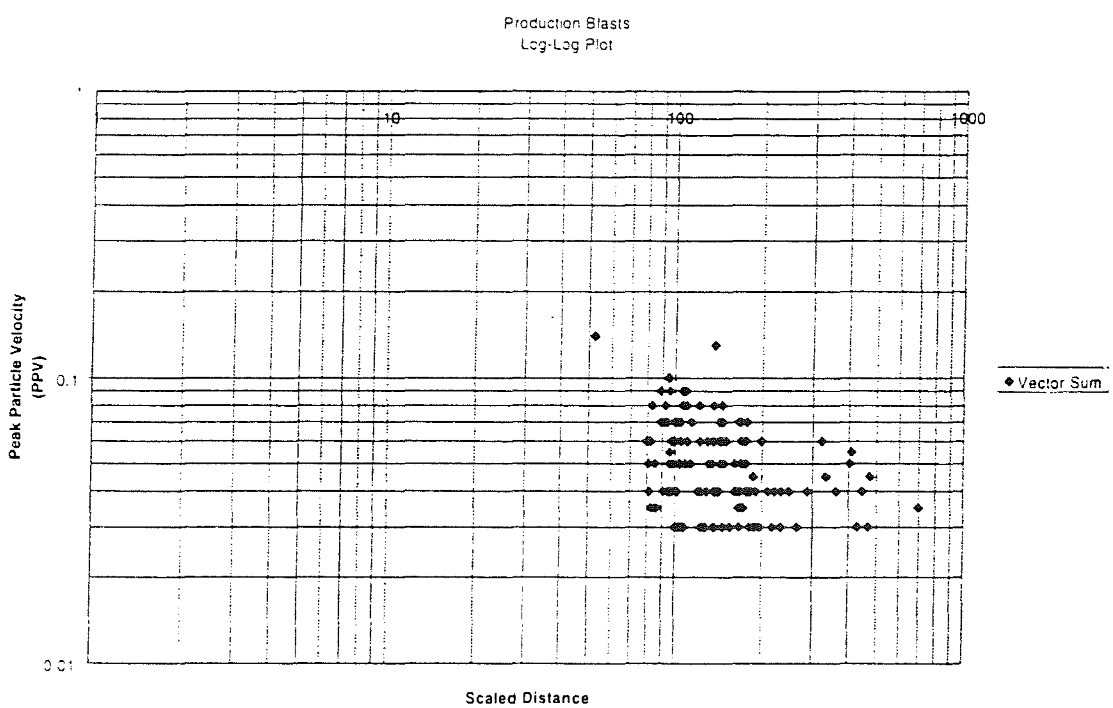

Figure 19: Vibrations vs scaled distance plot.

RESULTS

A total of 102 pre-split and production blasts were monitored at six cave instrument stations and at one exterior station. Of these blasts, 45 were of such scaled distances that the associated peak particle velocities failed to attain seismograph trigger levels of 0.03 in/s. The maximum value recorded in the cave was 0.13 in/s. This resulted from 48 pounds/delay at a distance of 940 feet and a total charge weight of 1272 pounds. The square root scaled distance was 135.0. Inspections of cave features near the seismograph stations and after each shot indicated no damage occurred. Neither fresh fall, new fractures, nor other suggestions of vibration damage were observed. Furthermore, a comparison of data resulting from cave traffic with that of the blasting revealed the former to have higher values.

CONCLUSIONS

The highway H realignment project was completed with no loss of time or additional expense attributed to blast monitoring or modification of blasting procedures. Blast vibration levels were kept to 25 percent of the potential damage threshold This resulted in preserving the integrity of Crystal Cave and with minimal interference of its commercial aspects. The instrumentation of the cave, the continuous monitoring of blast vibrations, and the cooperation of the Missouri Highway and Transportation Department, Journagan Company personnel, and the University of Missouri-Rolla personnel demonstrated blasting can be accomplished while considering environmental factors.

RECOMMENDATIONS

No further monitoring of Crystal Cave is recommended as blasting associated with the Highway H realignment has been completed. Thus, any vibrations occurring in the cave must be attributed to sources other than the construction associated with this project. The use of an independent blasting monitor contributed greatly to establishing amiable working relationships between the blasting contractor, the state, and those concerned with their property and/or the environment. The conduction of a pre-liaison conference with all involved parties present, established both communications and responsibilities prior to the beginning of construction. Similar procedures might be considered for similar future projects.

ACKNOWLEDGMENTS

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was most helpful in expediting instrument repairs. Special thanks are given to both Mesdames Vicki Snelson and Diane Henke, RMERC, for providing support services.

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