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Rock Blasting Fundamentals

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ROCK BLASTING, VIBRATION MONITORING, AND DAMAGE CONTROL IN URBAN AREAS

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ABSTRACT: The presence of deep injection wells in a county's water treatment plant (WTP) created a unique deterrent to a developer's plans for rock blasting, excavation, and development of 17 lakes in connection with the construction of an adjoining residential community and golf course in northeast Naples, Collier County, Florida, USA. Possibility of damaging vibrations from rock blasting operations, and potential impact to the integrity of the injection wells, required safety measures to be taken in developing the rock-blasting program to alleviate concerns of county representatives. A 4-stage investigative program consisted of rock characterization, pre- and post-blast survey, test blasts in the farthest lake area in an effort to develop some site specific baseline parameters. Resultant Peak Particle Velocity, Particle Displacement, and Peak Particle Acceleration (RPPV, PD, and PPA) was measured at various stations placed at selected distances from the test blast areas. Upon completion of the investigative program and issuance of restrictive permit, production rock blasting operations were performed under the full-time monitoring of the geotechnical consultant. This included setting up of multiple stations at various locations, including selected locations near the mobile home park property. Additional items included documenting the contractor's drill hole patterns, quantity of explosives detonated in a given shot sequence and millisecond delay period, monitoring station distance, and RPPV at the surface level. The engineered, inspected, properly planned, and tested program alleviated the concerns and provided a cost-effective method for rock blasting, excavation, and construction of these urban area lakes. More importantly, the test and production blasting operation and vibration (velocity, acceleration, and displacement) measurements provided noteworthy evaluations for close proximity development blasting near subterranean structures.

1.0 INTRODUCTION

A 142 hectare (350-acre) recreational/residential site, located in northeast Naples, Florida, USA, required construction of 18 lakes each approximately 6.1 m (20 ft) deep. Underlying rock throughout this site required blasting and removal prior to the development of these lakes. A county water treatment plant, located immediately south of this development with two built in deep injection wells created a deterrent to the developer's plan for rock blasting. Potential for damage to WTP structure and 2 deep injection wells contributed to the county's justifiable reluctance to grant permission and issuance of a permit for rock blasting operations. The project layout, identifying the salient features of the development, is illustrated in Figure 1.

2.0 PROGRAM

In response to the county's concern, the developer presented a 4-stage investigative program. The purpose of this technical program was to alleviate and technically address the justifiable concern of the property owners about the proposed rock blasting. It contained the following elements:

Stage 1 Conducting a site-specific rock characterization exploration program at the project site and in the initial test blast area.

Stage 2 Performing a pre-blast and post-blast survey of WTP and all structures located within a distance of 304 m (1,000 ft) from blast area by documenting visible interior and exterior defects. Additionally, conduct a pre-blast inspection of the 2 deep wells by performing Mechanical Integrity Testing.

Stage 3 Developing loading data and blast hole pattern from actual test blast in a proposed lake area at least 609 m (2,000 ft) away from WTP. Also, install a 12.2 m (40-ft) monitoring well, within 152 m (500 ft) of the blast area, to measure vibrations at the well bottom.

Stage 4 Providing full-time vibration monitoring services (documentation of RPPV, PD, PPA) during the production phase of the rock blasting and development of lakes.

Services of ASC geosciences, inc. (ASC) were retained by the client to provide consultation and to supervise the 4-stage program.

2.1 Stage 1 Investigation

This phase consisted of site specific rock characterization by performing geotechnical subsurface exploration, rock coring, geophysical profiling for an evaluation of rock and ground-water conditions including:

- Drilling a number of 6.1 m (20 ft) deep test borings in each of the 17 lakes.
- Developing time cutting profiles utilizing carefully controlled downward/rotational pressure on the tricone roller bit and recording cutting rate.
- Obtaining rock cores in selected lake areas.
- Performing Refraction Seismograph Velocity Profiling (RSVP) in certain lake areas between test borings.
- Conducting ultrasonic impulse velocity testing on rock cores.
- Establishing geological stratigraphy.

The rock layer was evaluated and sampled using two methods. The first technique involved a diamond-bit core barrel, which cuts an annular hole and retrieves the remaining "core" for laboratory observations and testing. The second

technique, commonly referred to as time-cutting, involved cutting a hole in the rock utilizing carefully controlled downward pressure on the tricone roller bit and rotational speeds and recording the cutting rate (minutes per seconds). Time-cutting gave a continuous profile of the rock hardness and, when used in conjunction with coring and other tests, it provided valuable information concerning relative

competency and hardness of the rock formation. Some core samples from the rock formation were sawed, trimmed and subjected to ultrasonic testing (commonly referred to impulse velocity test) under laboratory-controlled conditions. Measured P-wave velocity values from laboratory ultrasonic testing on saturated rock core samples of the limestone formations and calculated S-wave velocities ($V_s = 0.57V_p$) are presented in Table 1. They fall within the range for limestone.

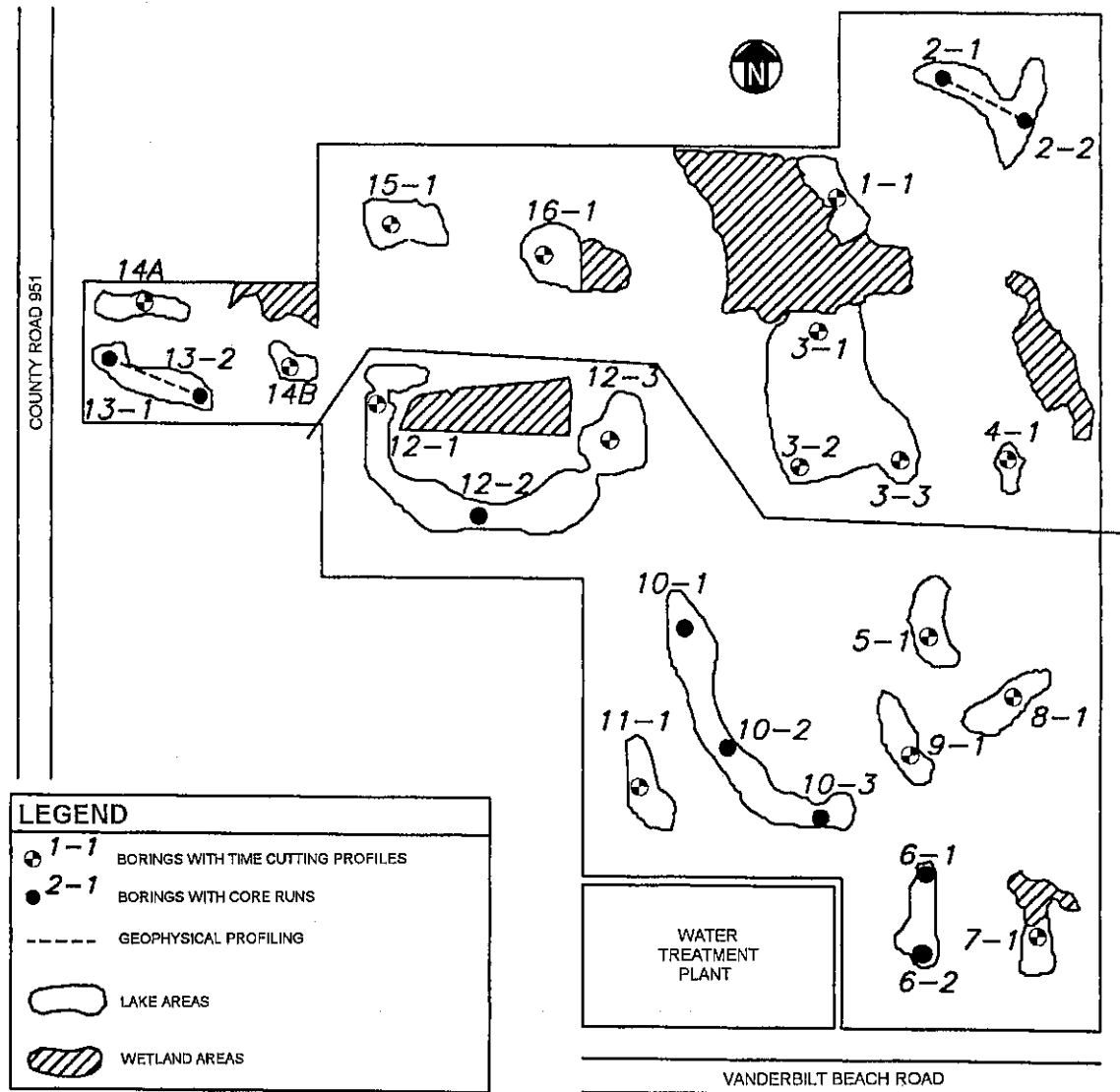


Figure 1. Project and Lakes Layout Plan with Boring, Coring, and Profiling Locations

The RSVP was conducted using seismic refraction procedure where geophones are placed along a straight line at a spacing of 1.5 m (5.0 ft) from each other. Each geophone was connected to a control cable, which in turn was connected directly to the seismograph. A trigger switch was also connected to seismograph. A seismic wave into the ground was generated by striking an aluminium plate with a hammer. This activated the trigger which, in turn, activated the seismograph and the subsequent seismic

waves detected by the geophones were recorded. The data obtained from these tests indicated that the P-wave (longitudinal wave) velocities of the upper caprock layer and lower weathered limestone layer ranged between 1,006 to 2,032 m/sec (3,300 to 6,666 ft/sec) and 762 to 1,310 m/sec (2,500 to 4,300 ft/sec), respectively.

Table 1. Ultrasonic Tests Summary

BORING NO	DEPTH (ft) ⁽¹⁾	L/D RATIO	P-WAVE VELOCITY (fps) ⁽²⁾	S-WAVE VELOCITY (fps) ⁽¹⁾
2-2	4.2 – 6.0 (upper limestone formation)	4.56	17,000	9,800
2-2	8.5 to 9.5 (lower limestone formation)	2.45	16,200	9,300
13-1	11.5 to 14.0 (lower limestone formation)	5.18	16,900	9,700
13-2	10.5 to 11.0 (lower limestone formation)	1.62	15,200	8,700

NOTES: ⁽¹⁾ S-wave velocity calculated as 57% of P-wave velocity with a Poisson's ratio of 0.25. ⁽²⁾ 1 ft = 0.3048 m

The locally available rock commonly referred to as Tamiami Formation throughout most of Collier County is composed of relatively thin, solution-riddled, highly permeable and very fossiliferous limestone. This shallow limestone layer is commonly referred to as “caprock” and is an authigenic limestone that occurs discontinuously throughout Collier County and portions of Lee County. It is a recent deposit that is not considered to be part of the Tamiami Formation (Saxena et al). A typical geologic stratigraphy of the proposed water management areas is illustrated in Figure 2.

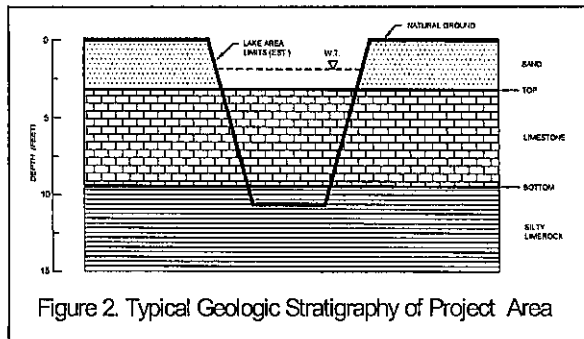


Figure 2. Typical Geologic Stratigraphy of Project Area

2.1.1 Findings, Comments, and Conclusions

Findings, comments, conclusions, and recommendations from Stage 1 investigations established that:

- Limestone thickness varied from 1.2 to 4.6 m (4 to 15 ft) thick across site.
- SPT “N” values were greater than 100
- Rock cutting time profile ranged from 30 sec to 9 min 30 sec utilizing vertical down pressure of 1,000 psi (68 atmospheres) on a 57 mm (2.25 in.) bit; percent recovery on 101 mm (4 in.) cores ranged from 70 to 100.
- RSVP indicated compression P-wave velocity of 1,524 to 2,134 mps (5,000 to 7,000 fps).
- Laboratory ultrasonic testing (impulse velocity) indicated P-wave velocity between 4,573 and 5,182 mps (15,000 and 17,000 fps) and S-wave velocity between 2,652 and 2,987 mps (8,700 and 9,800 fps).

- Variation in seismic velocity between field and lab tests is the result of vuggy nature in-situ versus the controlled and ideal conditions in laboratory (“field” vs “laboratory”).
- The vuggy limestone is commonly referred to as “caprock and/or cemented boulders” and is hard.
- Unless the rock was fractured by blasting techniques, it could not be excavated and removed by conventional excavation equipment.

2.2 Stage 2 Investigation

The purpose of the pre-blast survey was to inspect and document structures adjacent to the Vanderbilt Country Club project site, prior to the initiation of any blasting operations. The inspections were completed as part of Collier County requirements and served as documentation in the case of post-blasting claims. It consisted of conducting pre-blast inspections on 2 residential structures and buildings, in addition to inspection of the WTP. The inspections consisted of written descriptions of interior existing and observable defects together with photographs of exterior conditions.

This survey was done to determine the extent of any pre-blasting defects or damage to improvements located on adjacent properties as well as to comply with the county’s requirements.

2.3 Stage 3 Investigation

This consisted of the development of loading data and other baseline parameters with the following key elements:

- Select lake areas 1 and 2 far from the WTP but within the proposed project limits and perform test blasts.
- Examine rock blasting contractor’s development of drill hole patterns and determine quantities of explosives to be detonated in any given shot sequence and millisecond delay period (pounds per delay) while taking into consideration the distance and tolerable RPPV of 12.7 mm/ps (0.50 ips) as per Section 3.4.13.5.1 of the Collier County Land Development Code.
- Drilling of a 12.2 m (40 ft) deep monitoring test well to evaluate the levels of vibration occurring at the ground surface as well as beneath the surface. This was achieved by installing a special geophone (water-proofed) and the bottom of the 152 mm (6 in) pre-cased hole; installed to simulate the closest possible approach to deep wells.
- Conducting test blasts in Lake Areas 1 and 2 and measuring ground vibration levels produced as surface waves and identified as RPPV; measurements done at distances of 120 m, 185 m, 365 m, 455 m (400 ft, 600 ft, 1200 ft, and 1500 ft) from the blast site.
- Installing a number of seismographs near the blasting site during the duration of the blasting and 1 at the Collier County WTP, adjacent to the deep injection well.
- Developing a vibration monitoring program, encompassing test blasts and measuring RPPV at pre-determined locations from the nearest site.

2.3.1 Stage 3 Test Blasting Program

The test blasting program consisted of developing baseline parameters and a vibration monitoring program and included the elements listed below:

- Test rock blasting operations were performed in Lake Areas 1 and 2 with a total of 6 monitoring stations established at selected locations, including 1 at WTP.

- For the average lake excavation depth of 6.1 m (20 ft) and rock thickness of 3.6 to 4.2 m (12 to 14 ft), test blasting was performed utilizing a different scaled distance (SD) and pounds per delay.
- Millisecond delay blasting was used for effective rock fracture and safe RPPV.
- Specific velocity measurements were taken within a cased well by utilizing a downhole, watertight geophone; this additional monitoring was performed to alleviate the specific concerns raised by Collier County.
- A total of 10 blasts were performed and consisted of a total of 309 holes with depths ranging from 4.5 to 5.5 m (15 to 18 ft). Pounds per delay ranged from a minimum of 25 to a maximum of 70 and SD ranged from 42 to 261. A plot of RPPV versus SD for all test blasts was developed and is illustrated in Figure 3. A total of 51 readings were monitored. Deliberate and intentional blasts were performed to achieve a higher threshold and to obtain a good variation of RPPV that ranged from 2.5 to 31.7 mmmps (0.1 to 1.23 ips).

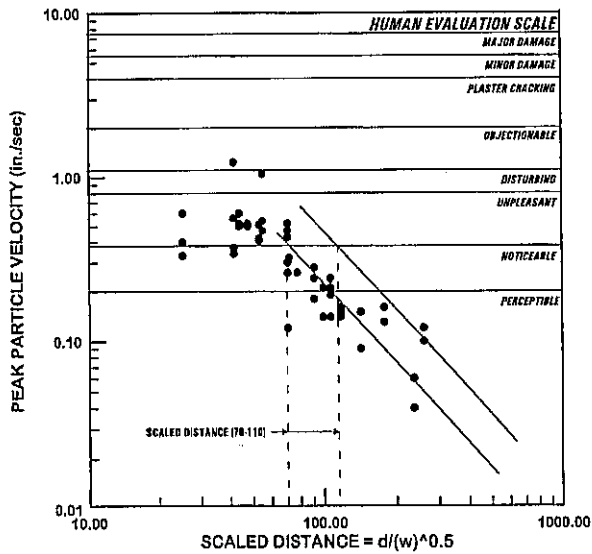


Figure 3. Test Blasting Data in Lakes 1 & 2

2.4 Stage 4 Investigation

Recommendations were developed from the Stage 3 program and recommended for Implementation in production blasting of the following items:

- In view of concerns raised by Collier County, use a conservative charge schedule and SD factor that would result in a RPPV of 7.37 mmmps (0.29 ips or 0.25 ips + 15%).
- For all blasting operations outside of the 304 m (1,000 ft) protection zone, use a minimum SD of 70 or above to keep the RPPV well below 7.37 mmmps (0.29 ips) at the WTP.
- For all blasting operations between 304 and 91.5 m (1,000 and 300 ft), use a SD of 100 to 130. A sliding scale is recommended in an effort to optimize RPPV and keep it well below the 7.37 mmmps (0.29 ips) threshold.
- Use a maximum number of holes, explosive charge, pounds per delay, as in Table 2.
- Maintain the already constructed isolation trench, 4.6 m (15 ft) deep and 91.4 cm (36 in.) wide, free of any debris in an area opposite the zone of influence between the blast area and the wells at WTP.
- Maintain full-time monitoring stations at both of the deep wells at the WTP and make sure that no blasting occurs within the buffer zone of 91.5 m (300 ft).

- Have the blasting contractor submit a daily blasting plan (for each blast) for review and acceptance by the consultant prior to initiation of any blasting.
- Institute a program whereby an immediate consultation and review is initiated whenever a RPPV of 7.37 mmmps (0.29 ips) is exceeded at the WTP from any blasting operations.
- Tabulated data is distributed to all concerned parties on a daily basis. Additionally, upon completion of all blasting operation, a pictorial, as well as a tabulated, summary of blast locations and readings noted at the WTP is submitted to the developer and distributed to all concerned parties.

2.4.1 Production Blasting Program

- Phase 1 Permit that county issued included all blasting outside of the protection zone of 304 m (1,000 ft) from the WTP. Production blasting operations were performed during early to mid 1998.
- Well over 100 blasts were conducted with full-time monitoring as well as review daily of blasting contractor's plan by the consultant.
- A total of 4 seismographs were placed at locations agreed upon among all interested parties.
- Range of measured RPPV values at WTP and adjacent horse ranch as well below the agreed upon threshold of 6.35 mmmps (0.25 ips).
- Rock in almost 65 acres of proposed lake areas, existing outside the protection zone, was effectively fractured without ever exceeding the RPPV threshold of 6.35 mmmps (0.25 ips).

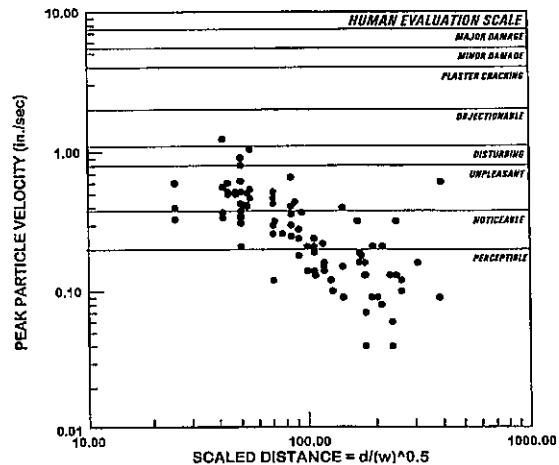


Figure 4. Test and Production Blasting Data Beyond 304 m (1000 ft) from WTP

Results of the production blasting test data at the WTP as well as beyond 304 m (1,000 ft) from the WTP are illustrated in Figures 4 and 5.

Table 2. Details of Production Blasting Program

DISTANCE IN FEET TO THE MONITORING STATION "d" (ft) ⁽¹⁾	SCALED DISTANCE D/(w ^{0.5})	MAXIMUM EXPLOSIVE CHARGE IN POUNDS PER DELAY TO BE DETONATED "w" (lbs) ⁽¹⁾	MAXIMUM POUNDS FIRED FOR [# HOLES] (lbs) ⁽¹⁾
1,000	130	60	3,000 [50]
900	125	50	2,500 [50]
800	120	45	2,025 [45]
700	110	40	1,600 [40]
600	100	35	1,400 [40]
500	100	25	1,000 [40]
400	100	15	300 [20]
300	100	10	200 [20]

NOTES: Blasting between 1,000 ft and 300 ft from Water Treatment Plant (WTP)⁽¹⁾ 1 ft = 0.3048 m; 1 lb = 0.45 kg; 1 in = 25.4 mm

3.0 GENERAL COMMENTS

The developer applied for a Phase II permit to blast lakes between 91.5 and 304 m (300 and 1,000 ft) of WTP and submitted all documentation from Phase I Production Blasting. Upon successfully completing a major portion of the Phase I blasting, the developer was denied a Phase II Blasting Permit for development of lakes between 91.5 and 304 m (300 and 1,000 ft). No specific reason was given by the County so an appeal was filed citing that scientific data provided with the Phase II application was sufficient to compel issuance of the permit. This only affected Lake 11 and portions of Lakes 6 and 10, totaling about 4 to 5 acres.

In the interest of time and economy, the developer elected to use special trenching equipment (Vermeer 955-T) and a backhoe (Caterpillar 375) to trench a 3.05 m

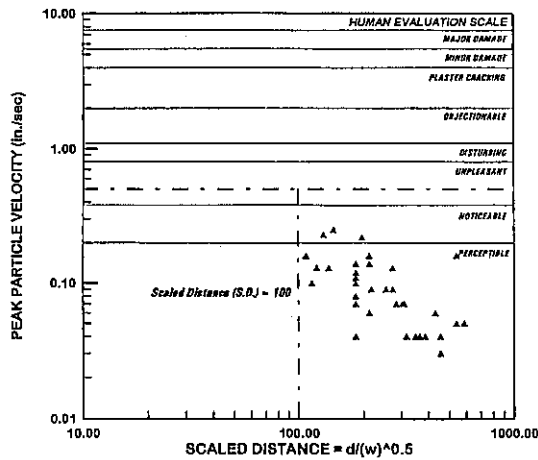


Figure 5. Test Production Blasting Data Beyond 304 m (1000 ft) from WTP

(10 ft) grid in the lake areas and break the rock with backhoes and hydraulic hammers. The project was completed on schedule and to the satisfaction of the developer.

4.0 CONCLUSIONS

To optimize the blasting work, it is necessary to carry out risk analysis in order to determine what is the intensity of vibration acceptance and, secondly, how large a charge can be blasted at a distance without exceeding the upset limit.

Site specific rock characterization program is a prerequisite to an effective rock blasting and vibration monitoring program (Saxena 1972).

Test blasting program should be conducted to determine the connection between vibration values, corresponding charges, and distances.

Test blasting loading schedule should be based on a SD of 100 for a limiting RPPV of 12.7 mm/ps (0.50 ips). If no test blasting is performed then SD of 150 should be used. A no blasting zone of 300 ft from any critical structure should be established in an effort to alleviate any blasting complaints.

Type of construction and condition of buildings within the risk zone should be determined by a pre-blast survey. Post blast inspections should be made during blasting operations and subsequent to their completion in those structures where claims are anticipated.

5.0 ACKNOWLEDGEMENTS

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