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Studies of the Pre-Buggy II Apparent Craters

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PROJECT PRE-BUGGY II
PNE-315F

STUDIES OF THE PRE-BUGGY II APPARENT CRATERS

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ABSTRACT

11 Five rows of five 1,000-pound charges and one row of thirteen 1,000-pound charges were detonated in ²the alluvial material at the Nevada Test Site. The charges were all fired at a depth of burst approximately 16% deeper than the optimum for radius for single charges except for two of the five-charge rows which were detonated approximately 32% deeper than optimum. For the five-charge rows, spacings of 0.94, 1.06, and 1.17 single charge crater radii were used. For the thirteen-charge row, spacings of 0.94, 1.17 and 1.40 single charge crater radii were used. The resulting craters showed that when the charges are spaced one single charge crater radius apart, the row crater averaged approximately 10% wider and 20% deeper than the crater from a single charge of the same weight detonated at the same depth, 16% deeper than optimum for single charge crater radius. At wider charge spacings, the row charge crater is both narrower and shallower. 2 When the spacing is about 1.30 single charge crater radii, the width of the row crater is about the same as the diameter of the corresponding single charge crater. When the spacing is about 1.22 single charge crater radii, the depth of the row crater equals the depth of the single charge crater. The cross section of the row charge craters at the shallower of the two charge depths appeared to be more nearly hyperbolic than parabolic as has been commonly assumed for the single charge crater. For a depth of burst 16% deeper than optimum for radius, the greatest volume per charge is excavated when the spacing is about 1.125 single charge crater radii. The lips along the sides of the row craters averaged about 2.4 times the average height of the lips around the single charge craters from the same charge weight at the same depth of burst. However, the lips at the ends of the row craters were generally smaller than those of the single charge crater,

and were quite irregular in vertical section. There appears to be an increase in the height of the lips along the sides of the row craters as the depth of burst is increased.

2 / Detailed discussion is given in variations of
charge spacing. 12 references / end

PREFACE

The Pre-Buggy II chemical explosive row charge cratering experiments were planned by Milo Nordyke of the Lawrence Radiation Laboratory's Plowshare Division in Livermore, in conjunction with Lt. Col. Ernest Graves, Jr., Director, U. S. Army Engineer Nuclear Cratering Group which had recently completed the Pre-Buggy I experiments. The Technical Director for the Project Pre-Buggy II was James Olson of the AEC Nevada Operations Office in Las Vegas. Donald G. Myers, LRL/Nevada, was H. E. Safety Coordinator. Principal responsibility for explosive assembly, emplacement, arming, and firing was that of Raymond S. Guido, K Division, LRL/Livermore. Mr. Guido was in charge of most field work.

Project Pre-Buggy II was fielded in two phases - in June and in August, 1963. The Architect-Engineer was Holmes and Narver, Inc., of Los Angeles, through their field office at the Nevada Test Site. Construction Support was provided by the Reynolds Electrical and Engineering Company Field Office at Mercury, Nevada, under supervision of LRL/Nevada Engineering and Construction Branch. Scientific photography was planned and executed by Lloyd E. Guymon and Jerry E. Wood, LRL/Nevada Photography Section. Aerial photography and topographic maps were made by American Aerial Surveys, Inc., of Covina, California.

The crater results were analyzed by J. L. Spruill and F. F. Videon of the Nuclear Cratering Group under the supervision of Milo Nordyke.

The magnetic ejecta studies raw data reported in Appendix D was gathered by R. S. Guido and J. Cottingham.

SYMBOLS AND DEFINITIONS

SINGLE-CHARGE CRATER NOMENCLATURE AND SYMBOLS

The nomenclature used for single charge craters is as follows:

Da . . . Maximum depth of apparent crater below preshot ground surface measured normal to the preshot ground surface.^a

Dal . . . Depth of apparent crater below average apparent crater lip crest elevation.

Dob . . . Normal depth of burst (measured normal to preshot ground surface).

Dt . . . Maximum depth of true crater below preshot ground surface.

Dtl . . . Depth of true crater lip crest below apparent crater lip crest.

Ejecta . . . Material above and or beyond the true crater and includes: (1) fallback; (2) breccia—ballistic trajectory; (3) dust—aerosol transport; etc.

Fallback . . . Material fallen inside the true crater and includes: (1) slide blocks; (2) breccia and stratified fallback—ballistic trajectory; (3) dust—aerosol transport; (4) talus; etc.

Hal . . . Apparent crater lip crest height above preshot ground surface.

Htl . . . True crater lip crest height above preshot ground surface.

Lac . . . Apparent crater lip crest.

Ltc . . . True crater lip crest.

Ra . . . Radius of apparent crater measured on the preshot ground surface.

Sa . . . Apparent crater surface, e.g. rock-air or rubble-air interface.

Sal . . . Apparent lip surface.

SGZ . . . Surface ground zero.

Sd . . . Displaced ground surface.

Sp . . . Preshot ground surface.

St . . . True crater surface, e.g. rock-air or rock rubble interface.

Va . . . Volume of apparent crater below preshot ground surface.

Val . . . Volume of apparent crater below apparent lip crest.

Vt . . . Volume of true crater below preshot ground surface.

Vtl . . . Volume of true crater below true crater lip crest.

Z . . . Vertical depth of burst (equivalent to dob when crater is formed on a horizontal surface).

ZP . . . Zero Point—effective center of explosion energy.

Note: The radius measurements pertain only to single charge craters and represent average dimensions. If crater shape deviates substantially from circular, the direction of measurement must be specified. An average radius value can also be determined by dividing the plan area by n and taking the square root.

Ral . . . Radius of apparent lip crest to center.

Rds . . . Outer radius of displaced surface.

Reb . . . Outer boundary of continuous ejecta.

Rlb . . . Outer radius of true lip boundary.

Rt . . . Radius of true crater measured on the preshot ground surface.

Rtl . . . Radius of true lip crest to center.

Rzt . . . Distance between the zero point and the true crater surface measured in any specified direction. When measured in a direction below the zero point is equivalent to lower cavity radius.

ROW CHARGE CRATER NOMENCLATURE AND SYMBOLS

Where appropriate, the same symbols and definitions given for the single charge crater are used for the row crater except that the principal letter of the symbol is changed to lower case as a means of differentiation. The following additional nomenclature and symbols are also used.

- s . . . Spacing between charges in a row.
- w_a . . . Width of apparent crater measured on the pre-shot ground surface.
- w_{al} . . . Horizontal distance (width) between lip crests on the sides of the crater.
- w_{ds} . . . Horizontal distance (width) between outer limits of displaced surface.
- w_{eb} . . . Horizontal distance (width) between outer boundaries of continuous ejecta on either side of the crater.
- w_{lb} . . . Horizontal distance (width) between outer limits of true lips on either side of crater.
- w_t . . . Width of true crater measured at pre-shot ground surface.
- w_{tl} . . . Horizontal distance (width) between true lip crests on either side of the crater.

CHAPTER 1

INTRODUCTION

1.1 SUMMARY

Project Pre-Buggy II consisted of the detonation of five rows of five charges each, one row of 13 charges, and four single charges, in Area 5 of the Nevada Test Site during June and August 1963. Each charge was 1,000 pounds of the liquid explosive nitromethane (NM) contained in a 36 inch diameter spun aluminum sphere.

1.2 OBJECTIVES

The purpose of Pre-Buggy II was to extend the knowledge of cratering with rows of charges in desert alluvium that had been gained from Project Pre-Buggy I^{*} (1).[†] Both experimental series were intended to provide data to be used in the design of the Project Buggy nuclear row charge experiment of the Plowshare nuclear excavation research program.

1.3 BACKGROUND

The excavation of ditches or linear craters with explosives has been a standard agricultural and engineering practice for many years. In most cases such excavation has used rows of evenly spaced charges of equal weight, detonated by either propagation or by individual electrical caps depending upon the wetness of the material. Experience has led to the development of rules for charge burial depth and spacing (2). Such rules, however, appear

* The first of the two Pre-Buggy experimental series was designated simply Pre-Buggy since, at the time it was planned, a second series was not contemplated. However, in this report it has been referred to as "Pre-Buggy I" to clearly distinguish between the two.

† Numbers in parenthesis designate references at the end of this report.

to be inappropriate for the design of excavations using nuclear explosive charges. In the use of conventional explosives on a small scale the governing economic consideration is obtaining the optimum size crater with the minimum weight of explosive. In nuclear excavation the goal is to obtain a crater of the desired size and shape with the minimum number of charges. This results from two economic factors inherent in nuclear excavation:

- a. The cost of emplacing the charges is a major part of the overall cost and is directly related to the number of charges, and
- b. The cost of the nuclear charges varies but slightly with their yield (3).

As a result of the differences in nuclear and conventional explosives, it was necessary to undertake basic research in row-charge cratering for the design of the nuclear row cratering experiments.

Beginning in 1958 and continuing through 1961, the Sandia Corporation fired a large number of row charges using charge weights of 2, 8, and 256 pounds (4) at their test area near Albuquerque. This work established the limits on charge spacing beyond which nonlinear craters are produced (a nonlinear crater is one in which the contribution of individual charges can be seen). They also obtained curves of row crater width, depth, and volume as a function of depth of burst (Dob) normalized to charge weight in pounds per foot of length and concluded "when the most efficient charge spacing was used, the optimum burial depth for row charges was 10% greater than the burial depth which optimized crater dimensions from a single charge of the same weight" (4).

In 1959, as a part of Project Toboggan, a series of line charge cratering experiments in the Yucca Dry Lake playa at the Nevada Test Site, five rows of 8-pound charges and one row of 256-pound charges were fired (5). These detonations indicate an equivalence between craters resulting from line charges and rows

of charges based upon the charge weight in pounds per foot of length. For rows of charges, this is obtained by dividing the weight of each individual charge by spacing between charges.

In 1961, LRL executed Project Rowboat in Area 10 of the Nevada Test Site (6). The project consisted of the detonation of seven rows of four 256-pound* charges and one row of three 256-pound* charges plus two single charges. The purpose was to extend the row-charge cratering experience to depths of burst deeper than optimum with larger charges. In the design of Project Rowboat, it was assumed that the spacing between the charges should be considered a function of the radius of a single charge crater of the same weight and depth of burst. The depths of burst selected were 1.0, 1.25, and 1.5 times the optimum for single charge crater radius, and the spacings were 1.0, 1.25, and 1.5 radii. The results showed that (6):

1. At a depth of burst just beyond optimum, single crater-radius spacing results in a smooth ditch with about the same crater dimensions as a single crater.
2. Increasing the spacing to 1.5-radius spacing results (in alluvium) in a reduction of depth to about one-half single crater depth while the radius is reduced only slightly.
3. At depths of burst greater than above, the crater becomes very poor with dimensions less than single crater dimensions regardless of spacing.

1.4 THE PRE-BUGGY EXPERIMENTS

The Nuclear Cratering Group (NCG) fired the Pre-Buggy I series of cratering experiments in Area 5 at NTS (the location is shown in Figure 1.1) in November and December 1962 and January

*Nominal charge weight. Actual charge weights averaged 278 pounds.

Figure 1.1 Location and vicinity map.

1963. The purposes were to refine then current knowledge of the effect of charge spacing and depth of burst upon crater dimensions from five-charge rows, and to investigate the effect of the parameter, crater depth/depth of burst, upon the fraction of vented radioactivity for both single and row charges.

The design of the Pre-Buggy I experiments was based upon the row cratering experience reviewed in the previous section and upon the experience gained from extensive research in cratering with single charges in desert alluvium at the Nevada Test Site over the previous 11 years. A sufficient number of single charges had been fired to clearly define the relationships between depth of burst and apparent crater radius and depth. Figure 1.2 shows the curves derived from a least squares fit to the cratering data resulting from the detonation of twenty-eight 256-pound charges at varying depths of burst. Analysis of cratering experience in desert alluvium with charges ranging in weight from 256 to 10^6 pounds led to a scaling relationship for crater dimensions based upon the 3.4th root of the charge yield (7). The cratering curves of Figure 1.2 and the $1/3.4$ relationship were used to relate the Pre-Buggy I results to the single charge cratering experience.

The charge weight used for the Pre-Buggy I experiments was 1,000 pounds. For a number of reasons (1), the liquid explosive nitromethane (NM) was selected for the charges instead of the cast TNT that had been used for previous cratering experiments. Nitromethane is a relatively insensitive commercial solvent which, when properly detonated, has explosive properties similar to TNT. The Pre-Buggy I charges were contained in 36-inch-diameter spun aluminum spheres and center detonated to represent as closely as possible a point source of energy. The charge design is illustrated in Figure 1.3. The booster assembly contained 5 pounds of Composition C-4 and two SE-1 special high

Figure 1.2 Single charge cratering curves for desert alluvium.

energy detonators, and a capsule containing the radioactive tracer, La^{140} . Details of the charge design, assembly, emplacement, and firing are given in Reference 8. The effectiveness of NM as a cratering explosive in comparison to TNT is discussed at length in Reference 9.

The basic detonation series consisted of six single charge events and four row charge events using five charges in each row. The series of six single charges was intended to normalize the results of the Pre-Buggy I experiments to the results of past experiments using TNT, and to permit a selection of the depth of burst and spacing for the row charges on the basis of crater size and fraction of radioactivity vented.

The apparent crater dimensions were determined from maps made by stereophotogrammetric techniques from aerial photographs.

Figure 1.3 The Pre-Buggy charge and emplacement.

True crater dimensions of three single charge and two row charge craters were measured using colored sand columns.

The dimensions of the single charge craters are given in Table A.1 (Appendix A). Scaled to 256 pounds by the 3.4th root of the charge weights, they were in reasonable agreement with the cratering curves of Figure 1.2 and fell well within the scatter of the 256-pound data. Based upon the results of the single charge events, a depth of burst of 19.8 feet was selected for the row charges. The charge spacings became:

Event A 20.6 feet = 1.0 single charge crater radius

Event B 30.9 feet = 1.5 single charge crater radii

Event C 25.75 feet = 1.25 single charge crater radii

Event D 23.2 feet = 1.125 single charge crater radii

The row charge apparent crater dimensions, determined from the topographic maps, are given in Section 2 of Appendix A. The data showed that:

a. Linear rows with smooth sides could be produced by the detonation of rows of charges buried slightly deeper than optimum for single charge crater radius at spacings between 1.0 and 1.5 single charge crater radii.

b. As the spacing was increased from 1.0 to 1.5 R_a the crater width decreased slightly while the depth dropped from 12.1 to 4.9 feet.

c. For a charge spacing, s , less than about 1.15 radii, the row crater width was greater than the diameter of the corresponding single charge crater; for s less than about 1.05 R_a row crater depth exceeded single charge crater depth.

1.5 DESIGN OF THE PRE-BUGGY II EXPERIMENTS

The Pre-Buggy II series of experiments was designed to extend and refine the results of the Pre-Buggy I series. The Program of detonations is given in Table 1.1. The primary purpose

was a study of the dimensions and geometry of the apparent craters resulting from the detonation of row charges. No studies of the true crater and its zones of deformation were planned, nor were any radioactivity studies included. However, minimal programs for the study of ground surface motion, cloud and base surge growth, and ejecta were planned.

TABLE 1.1 PRE-BUGGY II DETONATION PROGRAM

Shot	Number of Charges	Explosive		Dob (ft)	Spacing (ft)	Spacing (radii)
		Type	Weight (lb)			
Row C	5	NM	1,000	19.8	20.6	1.000
Row G	5	NM	1,000	19.8	23.2	1.125
Row D	5	NM	1,000	19.8	25.75	1.250
Row B	5	NM	1,000	23.0	20.6	1.000
Row C-Prime	5	NM	1,000	23.0	20.6	1.000
Row H	13	NM	1,000	19.8		
			First four spaces:		20.6	1.000
			Second four spaces:		25.75	1.250
			Third four spaces:		30.9	1.500
Array F	2	NM	1,000	19.8		
	2	TNT	950	18.6		

1.5.1 Crater Studies. The crater studies program of Project Pre-Buggy II had the following objectives:

- a. To confirm the results of the Pre-Buggy I series by repeating the row charge detonations, and to indicate the scatter of the data that might be expected.
- b. To study the effect of varying the depth of charge burial and to further define the effect of charge spacing upon the dimensions and geometry of craters produced by row charges.
- c. To investigate further the unique geometry of row charge craters.

The planned contribution of each of the detonations to this program is as follows. Rows C, G, and D repeated three rows of the Pre-Buggy I series at spacings of 1.0, 1.125, and 1.25 single charge.

crater radii to confirm their results and to indicate the scatter to be expected from the 1,000 pound row charges. Row B introduced a Dob 16% deeper at the same spacing for comparison with Row C. Row C-Prime was planned to study the problems associated with joining two sections of a nuclear excavation project. To prevent the first charge of the second section from venting prematurely into the existing crater, a deeper depth of burst was used, and to permit comparison with a separate five-charge row, the same Dob as Row B was selected. Row H repeated the spacings of Rows C and D and added a 1.5 radius spacing. The purpose was to investigate the effect of more than five charges in a row and the smoothness of the transition between sections of differing charge spacings. The spacings selected permitted comparison with the five-charge rows at the same spacings of Pre-Buggy I and Pre-Buggy II.

1.5.2 Ground Motion. Ground surface motion was recorded by means of high-speed motion picture photography of flares mounted on wooden stands placed in a row over the line of charges. Two camera stations for each shot, one 1,000 feet south and one 2,000 feet west of each charge array, with another camera in an orbiting helicopter overhead, were used to photograph each detonation. Details of the scientific photography are given in Appendix C.

1.5.3 Cloud and Base Surge. Photography of the main cloud and base surge formation, growth, and diffusion with time was obtained from the same camera stations. The photography was planned to permit a comparative study of the main cloud and base surge from both single and row charges to be made. A separate report will be issued.

1.5.4 Ejecta Studies. A study of the ejecta from the craters using magnets buried at varying depths in the backfill of the emplacement holes and placed in lines along the surface was made. Magnets were used in three of the 13 holes of Row H and in two of the single charge holes (one TNT and one NM) of Array F. The magnets were coated with a plastic material to reduce their density to approximately that of the alluvium. The data resulting from the ejecta study are given in Appendix D.

CHAPTER 2

PROCEDURE

2.1 SITE

2.1.1 Location and Arrangement. The site selected for Project Pre-Buggy II was immediately to the south of the Pre-Buggy I site. Its location is shown in Figure 1.1. An area approximately 1,600 feet east-west by 500 feet north-south was cleared and graded, and two charge lines running approximately east-west and 250 feet apart were surveyed in. Figure 2.1 is a plan of the site showing the specific location and arrangement of each charge array.

Figure 2.1 Site plan and layout of charge arrays.

2.1.2 Soil Data. No soils tests were made for Pre-Buggy II since testing had been done in the same area for Pre-Buggy I. The area is a typical desert alluvial fan. The soil is classified as a

gravelly sand, well graded, with some silt and occasional cobbles and boulders. Boulders up to 18 inches in diameter were noted in excavation of some of the emplacement holes and around the craters. Visual examination of the mechanically excavated trenches of Pre-Buggy I showed considerable stratification, with layers ranging from a few inches to two feet in depth. In-place tests indicated dry densities ranging from 80 to 120 pounds per cubic foot, and moisture contents ranging from 4 to 7%. The distribution of cobbles and boulders was not uniform, the area being crossed by several dry washes. Excavation and craters also revealed evidence of older, subsequently covered, dry wash beds having large concentrations of rounded and subrounded cobbles and boulders.

2.2 CHARGE DESIGN

The Pre-Buggy II explosive charges were identical to those designed and used for Pre-Buggy, except that the radioactive source insertion tube was omitted. The assembly of a charge is described in detail by Rooke and Davis in Section 2.1.1 of PNE 302 (8).

2.3 EMPLACEMENT AND FIRING

2.3.1 Excavation and Casing. The horizontal location of each charge was surveyed to the nearest hundredth foot and marked with a stake, and the undisturbed ground surface elevation at that point was determined to the nearest hundredth of a foot. Forty-eight-inch-diameter emplacement holes were excavated, using a truck-mounted bucket auger, to a depth about two feet deeper than the desired depth of burst. The material removed in the excavation of each hole was carefully piled nearby. The top 4-foot portion of each emplacement hole was cased with 48-inch corrugated metal pipe to prevent caving. In most cases, the top of the casing protruded a few inches above the undisturbed ground

surface. After the emplacement holes had been drilled and cased, hubs were set by a survey party at a point on either side of the casing to establish a known elevation in relation to the undisturbed ground surface elevation.

2.3.2 Charge Placement. Each charge container was assembled in Sugar Bunker (see Figure 1.1) to include the booster assembly and all firing lines and placed in a specially constructed wooden cradle. The cradle, with the assembled charge container, was hauled on an H. E. truck to the emplacement hole. The cradle and charge container were unloaded by hand and placed on a piece of plywood used as a cover over the emplacement hole. An electrical continuity check of the charge firing system was made, and a surveyor's tape was attached to the top of the charge. Another truck having a front-mounted A-frame and winch was moved into place over the hole and the charge container connected with 3/4-inch rope by means of the two lifting eyes built into the top plate of the sphere. The container was raised, the cradle and plywood cover removed, and the charge slowly lowered until its center was at the desired depth of burst.

The proper depth of burst for each charge was determined by (1) averaging the surface ground zero (SGZ) elevations, previously determined by survey, at each emplacement hole of the charge array, (2) subtracting from the average SGZ elevation the depth of burst for that array to obtain the charge elevation, and then (3) subtracting the charge elevation from the SGZ elevation at each emplacement hole to determine the specific depth of burial for each charge. The depth to which each charge had been lowered was measured on the tape attached to the charge container with a straightedge laid across the survey hubs. When the container was at the desired depth another continuity check of the detonators and cables was taken.

A natural dry sand of construction quality was shovelled into the hole and tamped carefully in place under and around the charge container until it was securely seated and the sand had completely covered the container. The winch was then released to relax the tension in the rope sling until the weight of the container rested fully on the sand, then tension was again taken up in the lines.

A second H. E. truck, a pickup, carrying two 55-gallon drums of nitromethane was backed into place beside the emplacement hole opposite the winch truck. The drums of nitromethane had been weighed at the NTS Storage Yard in Area 5 where they were stored, the drums numbered, and the weights recorded. Each drum contained about 500 pounds of NM. A Tygon tubing fill line with a plastic valve was attached to the bung of one of the drums and an elbow-shaped vent line attached to its vent while it was in the upright position. The drum was then tipped over to the horizontal position, its top extending over the tailgate of the pickup, the plastic valve opened, and the drum drained into the sphere. The process was repeated with the second drum, and the filling of the sphere completed. When the charge was full, the fill and vent lines were dropped into the emplacement hole and permitted to drain and collapse. The empty drums of NM were returned to the storage yard where they were again weighed and recorded.

Tension on the rope lines was slowly relaxed until they were slack. A final reading of the charge depth was made, and the ropes were cut. In some cases the final charge depth differed by as much as a foot from the planned depth of burst because the rope stretched or the charge container rose as the sand was placed in the hole for seating the charge, or because the charge container settled as it was being filled with NM. Final depths of burst and charge weights are given in Appendix B, Section 1. The numbering of the individual charges is shown in Figure 2.2.

Figure 2.2: Arrangement and numbering of charges.

2.3.3 Stemming. The charges were stemmed with the natural material that had been removed from the emplacement holes as they were excavated. It was screened to remove all cobbles and gravel over two inches in diameter. In stemming all holes except those in Row D, small amounts of water were added to reduce the dust in the hole and improve compaction. The material was placed in lifts that averaged two feet deep and was hand tamped using a locally fabricated 35-pound tamper having a flat steel plate on the bottom approximately one inch thick and six inches square. No attempt was made to maintain close control over water content or tamping effort other than the use of repetitive procedures in placing and tamping the material. During stemming, the detonator leads, encased in plastic tubing, and the primacord backup firing lines were led up through the stemming material. The primacord was coiled at the bottom of the last lift to prevent its ignition flash from obscuring the flares in the scientific photography. When the stemming reached the bottom of the casing, the casing was pulled, and the stemming completed. After a continuity check of the leads had been made, the ends were led into a small metal box fitted with a hasp and padlock which was then locked for safety. The keys were kept in the possession of the senior H. E. technician. After all charges in a row were in place, the ground surface over the charge array was leveled and, just before shot time, the area was sprayed with water to reduce the dust.

2.3.4 Arming and Firing. The firing system is illustrated schematically in Figure 2.3. After all else was ready, the main firing cable and an eight-conductor control cable for charging the capacitor bank were run from the firing trailer to the capacitor discharge unit (CDU) location approximately 75 feet from the charge array. All connections were made and the system was dry run. If the dry run was successful, the main firing line and

control cable were sandbagged for a distance of approximately 100 feet from the CDU toward the firing trailer. The CDU was placed in a wooden box which in turn was placed in a steel box. Sandbags were stockpiled to be used in sandbagging the CDU boxes.

Figure 2.3 Schematic diagram of firing system.

Upon authorization from the Technical Director or his field representative, final connection of the detonator leads to the C-cables was made. Upon radioed receipt of orders to arm, the arming party connected the C-cables to the CDU, the CDU high voltage was unlocked, the steel cover put on the box, and the box sandbagged. The arming party then returned to the firing trailer. The Remote Control/Trigger Unit was unlocked, and upon orders from the Technical Director or his field representative, a 10-minute voice countdown was begun on the public address system and radio. At H - 5 minutes the high voltage was energized manually, and at H - 2 minutes the automatic control unit (a Wollensack Goose) was started. At -3.0 seconds the two remote camera stations were started, at -0.3 second the flares or flash-

bulbs were fired, and at zero time the CDU was triggered. The same signal triggered a zero time fiducial flashbulb to record on the film the exact zero time.

After each detonation the arming and firing party checked the crater for misfires and reported all clear. There were no misfires, and the alternate firing system was not needed.

2.3.5 Detonation Record. The experimental series was carried out in two phases. The first, from May 28 through June 13, was the detonation of five rows of five charges each; the second, in August, was the detonation of one row of 13 charges, and one detonation of four widely separated individual charges, two 1,000-pound NM and two 950-pound TNT. The time and date of each shot were:

<u>SHOT</u>	<u>TIME (PDT)</u>	<u>DATE</u>
Row C	1243	May 28, 1963
Row G	1500	June 5, 1963
Row D	1315	June 7, 1963
Row B	1200	June 11, 1963
Row C-Prime	1440	June 13, 1963
Row H	1425	August 2, 1963
Array F	1530	August 6, 1963

Meteorological data for each detonation, recorded by a mobile weather station established in Area 5 for the project, is given in Appendix B, Section 2.

2.4 MEASUREMENT OF THE CRATERS

2.4.1 Dimensions. The dimensions of each crater were determined by comparison of preshot and postshot topographic maps of the crater area. The maps were prepared by stereophotogrammetric methods from aerial photography. The preshot

photography of the entire area was flown on May 13, 1963. The postshot photography was taken immediately after each detonation. The widths, depths, and lip heights of the row craters were averaged over the center three-fifths of the crater (or the center three-fifths of that portion of the crater having a given spacing in the case of Row H), from half way between charges 1 and 2 to half way between charges 4 and 5, or, from Station 1.5 to Station 4.5. This was the portion of the row assumed to be approximately linear and free from any "end charge" effect, and thus representative of a section of an infinitely long row of charges having that spacing and Dob.

Widths were determined as follows:

- a. By comparing the preshot and postshot topographic maps of the crater area, the line of intersection of the apparent crater with the preshot ground surface was established.

- b. The area bounded by these lines of intersection and on each end by a straight line through Stations 1.5 and 4.5 perpendicular to the centerline of the row of charges was measured with a planimeter.

- c. The area so determined was divided by the horizontal distance from Station 1.5 to 4.5, equal to three times the charge spacing (3s), to obtain the average width of the linear portion of the crater.

This process is illustrated in Figure 2.4.

The average depth of the center three-fifths of each row crater was determined as follows:

- a. A broken profile was drawn through the deepest points in the center three-fifths of the crater, and a similar profile was drawn of the preshot ground surface directly above each point of the bottom profile.

- b. The area bounded by the two profiles and by vertical lines through Stations 1.5 and 4.5 was measured with a planimeter.

Figure 2.4 Method used to determine average apparent widths and depths of the row charge craters.

c. The area so determined was divided by three times the spacing to get the average depth of the linear portion of the crater. See Figure 2.4.

Apparent crater volumes were determined by measuring the area within each contour in the crater, multiplying the area by the contour interval, and summing. The bottom portion was treated as a parabolic section or as a paraboloid. The top elevation was determined by averaging the preshot spot elevations within the apparent crater.

The average heights of the lips on the side of each row crater were determined in a manner analogous to that described for determining the average depths.

To measure the volumes of the apparent lips, cross sections were drawn at the shot points and midway between shot points, the area on each cross section between the apparent lip and the preshot ground surface was measured using a planimeter, and the volumes then determined by the end area method.

For the four single charge craters, the average radii were determined by measuring the area within the horizontal projection of the intersection of the apparent crater with the preshot ground surface and solving for the radius of a circle having the same area. For each single charge crater, the depth was taken as the difference in elevation between the deepest point in the crater and the preshot ground surface directly above that point. The average lip height for each single charge crater was determined by (1) measuring the area between a cylindrically projected profile of the preshot ground beneath, and (2) dividing the area so obtained by the horizontal length of the profiles.

2.4.2 Crater Irregularity. One of the objectives of the crater studies program was to determine the charge spacing beyond which linear craters were no longer produced. To permit comparison of

irregularity, or departure from linearity, between craters it was necessary to define an index of irregularity. To this index was assigned the symbol I . I_w , I_d , and I_h denote the irregularity associated with the width, depth, and lip heights, respectively, of the linear portion of a crater. The definition of irregularity and the method of its determination are illustrated in Figure 2.5.

Figure 2.5 Definition and determination of percent irregularity.

CHAPTER 3

RESULTS

3.1 GENERAL

An aerial view of all Pre-Buggy craters is shown in Figure 3.1. All of the row charges produced V-shaped craters with relatively straight, flat sides. The center portions of the row craters were roughly linear. The row craters had massive lips on the sides and relatively insignificant lips on the ends. Apparent crater and lip dimensions and volumes are given in Tables 3.1 through 3.4. The preshot and postshot topographic maps of the crater areas and craters are reproduced at a reduced scale in Appendix B, Section 2. The craters are described in the following paragraphs.

3.2 CRATERING RESULTS

3.2.1 Row C. The first row charge to be fired, Row C, was fired at a depth of 19.8 feet, approximately 16% deeper than optimum for 1,000-pound charges. The charges were spaced 20.6 feet apart. This spacing had been selected in the Pre-Buggy I experiments as the apparent crater radius that would be expected from a single 1,000-pound charge detonated at 19.8 feet in the alluvium. The resulting crater had an average width of 49.5 feet and an average depth of 15.4 feet. The north lip averaged 5.41 feet in height; the south lip, 6.86 feet. In section, the crater was V-shaped with flat sides and the point of the vee rounded. The cross-sections of the crater at the shot points and at each end are plotted as Figure 3.2. The longitudinal profile and the lip profiles are shown in Figure 3.3, and Figure 3.4 is an aerial view of the crater. The central portion of the crater and lip, between Stations 1.5 and 4.5, was quite regular in shape. The irregularity in width, I_w , was 2.5%, the smallest value of all the

Figure 3.1 Aerial photograph of all Pre-Buggy craters.

TABLE 3.1 ROW CHARGE CRATER DIMENSIONS, PRE-BUGGY II

Row	Dob (ft)	s (ft)	w _{avg} (ft)	w _{max} (ft)	w _{min} (ft)	I _w (%)	d _{avg} (ft)	d _{max} (ft)	d _{min} (ft)	I _d (%)
B	23.0	20.6	46.2	49.7	42.5	5.8	7.6	8.8	5.6	11.
C	19.8	20.6	49.5	50.9	46.4	2.5	15.4	16.1	13.5	3.0
C-Prime	23.0	20.6	40.6			4.1	9.3			8.3
D	19.8	25.75	46.8	48.5	42.9	3.5	11.7	13.7	9.4	6.8
G	19.8	23.2	47.3	48.7	45.0	3.5	13.7	14.0	12.5	2.7
H-1	19.8	20.6	49.5	51.4	45.8	2.7	14.7	15.5	13.8	4.5
H-2	19.8	25.75	46.7	49.0	45.2	3.7	13.0	14.9	11.7	3.1
H-3	19.8	30.9	40.2	42.5	36.2	5.2	10.5	11.2	9.6	4.0

TABLE 3.2 SINGLE CHARGE CRATER DIMENSIONS, PRE-BUGGY II

Event	Explosive	Weight (lb)	Depth of Burial (ft)	Scaled Depth of Burial (ft/kt ^{1/3.4})	R _a (ft)	D _a (ft)
F-1	Nitromethane	1,000	19.8	185	22.7 ± 0.9	11.8
F-2	Nitromethane	1,000	19.8	185	21.2 ± 1.8	11.8
F-3	Cast TNT	950	18.5	175	21.1 ± 0.6	11.0
F-4	Cast TNT	950	18.33	176	22.1 ± 0.8	10.8

TABLE 3.3 LIP HEIGHTS, PRE-BUGGY II

Row or Event	Spacing (ft)	Dob (ft)	South Lip				North Lip				Avg. of N. & S. Lips (ft)
			h _{max} (ft)	h _{min} (ft)	h _{avg} (ft)	I (%)	h _{max} (ft)	h _{min} (ft)	h _{avg} (ft)	I (%)	
B	20.6	23.0	9.7	5.2	7.95	5.1	6.8	5.0	5.97	2.8	6.96
C	20.6	19.8	7.5	5.8	6.86	2.4	6.4	4.5	5.41	3.2	6.14
C	20.6	23.0	7.8	5.6	6.69	4.3	9.1	5.5	7.83	7.2	7.26
D	25.8	19.8	8.4	5.3	7.06	4.2	8.1	6.4	6.96	4.2	7.01
G	23.2	19.8	8.9	6.0	7.57	4.6	7.9	4.8	6.54	7.5	7.06
H-1	20.6	19.8	7.4	4.4	5.89	6.3	7.4	4.8	5.68	6.0	5.78
H-2	25.8	19.8	6.3	4.5	5.48	4.4	6.8	5.5	6.12	2.0	5.80
H-3	30.9	19.8	7.5	5.3	6.53	3.7	5.3	3.0	4.49	7.0	5.51
F-1	-	19.8				Single Crater					2.78
F-2	-	19.8				Single Crater					2.56

TABLE 3.4 APPARENT CRATER AND LIP VOLUMES, PRE-BUGGY II

Event	Crater Volume		Lip Volume	
	Gross (ft ³)	Linear Portion ^a (ft ³)	Gross ^b (ft ³)	Linear Portion (ft ³)
B	23,950	14,720	33,820	20,030
C	41,420	26,470	50,180	29,240
C ¹	-	14,500	-	18,570
C + C- Prime	71,460	24,171	75,290	-
D	47,775	27,865	59,830	36,020
G	43,060	27,400	52,130	30,050
H-1	-	26,110	-	28,140
H-2	-	17,860	-	17,630
H-3	-	14,950	-	14,650
H	107,780	-	117,120	-
F-1	7,860	-	10,170	-
F-2	6,030	-	13,080	-
F-3	6,950	-	-	-
F-4	7,560	-	-	-

^a Measured between Stations 1.5 and 4.5 in the five-charge rows.

^b The volume of the apparent lip above the preshot ground surface.

Figure 3.2 Row C crater cross sections.

Figure 3.3 Row C crater longitudinal profile.

Figure 3.4 Aerial view of Row C crater.

row craters, and the irregularity in depth, I_d , was 3.0%. The irregularity of the crater lips was 3.2% for the north lip and 2.4% for the south lip.

3.2.2 Row G. The second row charge fired, Row G, was at the same depth of burst as Row C, 19.8 feet, but had a charge spacing of 23.2 feet. The crater averaged 47.3 feet in width and 13.7 feet in depth and was thus slightly smaller than Row C. The lips of Row G, on the other hand, were larger than those of Row C, averaging 7.06 feet as opposed to 6.14 feet for Row C. The crater was less regular in its width than was the Row C crater, but it was the most regular of all the craters in depth, with an irregularity of only 2.7%. In Figure 3.5, a photograph of the interior of the crater, the flatness of the sides slopes is quite apparent. Figures 3.6 and 3.7 are the cross sections and the

Figure 3.5 Interior of Row G crater viewed from the west.

Figure 3.6 Row G crater cross sections.

Figure 3.7 Row G crater longitudinal profile.

longitudinal profile of the crater. Figure 3.8 shows the crater from the air.

Figure 3.8 Aerial view of Row G crater.

3.2.3 Row D. The arrangement of charges for Row D differed from the first two rows fired only in the spacing. In Row D it was 25.75 feet, which was assumed to be 1.25 single crater radii. The resulting crater was one-half foot narrower and two feet shallower than Row G. It was also slightly more irregular in its central portion than the craters at a closer spacing. The east end of the crater is 5.5 feet wider and about 5 feet deeper

than the west end (see topographic map in Appendix B, Figure B.3.13). Figure 3.9 is a view of the crater from the west end. The plane sides are apparent, but there is a larger rounded area in the bottom than in Row G. Note also the almost complete absence of a lip on the near end. At one point on the near (west) end of the crater, the postshot ground surface was below the pre-shot surface. The more typical end lip is seen on the far end. It may be contrasted with the lips on the sides. Typical cross sections are shown in Figure 3.10. Figure 3.11 shows the longitudinal profile and Figure 3.12 shows an aerial view.

3.2.4 Row B. The fourth row charge fired, Row B, was at a depth of burst of 23 feet, about 1.32 times optimum depth of burst for radius. The spacing was the same as that used for Row C, 20.6 feet. The shape of the crater strikingly demonstrates the effect of the deeper charge burial. Figure 3.13 shows the crater as seen from the west end. It is quite shallow and almost parabolic in cross section (Figure 3.14), with higher lips on the sides than those of the craters at the shallower depth of burst. The average depth was 7.6 feet compared with 15.4 feet for Row C at the same spacing but with the charges buried 3.2 feet shallower. There is less difference between the average width of Row B, 46.2 feet, and the 49.5 feet width of Row C. The average lip height on the sides of the center three-fifths of the crater was 7.0 feet for Row B compared with 6.1 for Row C. Figure 3.15 shows the profiles of the crater and the lips. Figure 3.25, an aerial view of the single charge craters, includes the Row B crater.

3.2.5 Row C-Prime. This row was fired as an extension of the Row C crater. Its Dob and spacing were the same as those used for Row B. The purpose of the detonation was to repeat the Row B crater as well as to investigate the problems that might be encountered in joining sections of a waterway or cut when

Figure 3.9 Row D crater viewed from the west.

Figure 3.10 Row D crater cross sections.

Figure 3.11 Row D crater longitudinal profile.

Figure 3.12 Aerial view of the Row D crater.

Figure 3.13 Row B crater viewed from the west end.

Figure 3.14 Row B crater cross sections.

Figure 3.15 Row B crater longitudinal profile.

reasons of safety or construction convenience dictated using several separate detonations. The emplacement hole for the charge closest to Row C was dug at the same time as those for Row C and filled with sand during the Row C detonation. Afterward the sand was removed and the hole cleaned out for the emplacement of the first charge in Row C-Prime. A sequence of frames from a film of the C-Prime detonation is shown in Figure 3.16. A few milliseconds after firing, the end charge of Row C-Prime began to vent through the end of the Row C crater. It developed into an excellent example of directed blast. The mound over the other charges continued to rise, and they later vented upward. The longitudinal profile and cross sections are shown in Figures 3.17 3.18. The more or less uniform slope of the C-Prime crater downward toward the Row C crater apparently results from the early venting in that direction. The cavities apparently coalesced at about the time of, or perhaps just prior to, the beginning of the end vent, and the escaping gases scoured material from the bottom of the crater in that direction. The detonation of C-Prime deposited approximately 2,200 cubic feet of throwout material in the linear portion of the Row C crater. A portion of the throwout was from partial failures of the side slopes of Row C crater. The average width of the center or linear portion of the Row C crater increased from 49.5 to 52.4 feet at the preshot ground surface. It is interesting to note in Figure 3.17 that the throwout in the bottom of the Row C crater begins at a point 1.5 feet east of the first charge of Row C, or about 22 feet from the last charge of Row C-Prime, and reaches its greatest depth about 48 feet from the end charge of C-Prime. The topographic map of the crater (Figure B.3.12) shows a saddle of material that has been deposited in the Row C crater. The saddle is quite apparent to an observer on the crater lip, and is also visible in Figure 3.19 which is an aerial photograph of the Row C/C-Prime crater. The shape and dimensions of the

Figure 3.16 Film sequence showing Row C-Prime venting into the Row C crater.

Figure 3.17 Row C/C-Prime longitudinal profile.

Figure 3.18 Row C-Prime cross sections.

Figure 3.19 Aerial view of the crater from Rows C and C-Prime.

Row C-Prime crater are somewhat different from those of Row B at the same depth of burst and spacing. The average width of the center three-fifths of the Row C-Prime crater is 40.6 feet compared with 46.2 feet for Row B, and the average depth is 9.3 feet which compares with 7.6 feet for Row B. The disparity in average dimensions results from the greater width and depth of the crater at the east end where it joins the Row C crater which probably result from the scouring action mentioned above.

3.2.6 Row H. Row H was a row of 13 charges, all at the same depth, but at three different spacings. It was intended to provide a comparison with the Row C and Row D craters at 1.0 and 1.25 assumed single charge crater radii, respectively, but with only five charges each, and to demonstrate the effect of varying the spacing within a single row of charges without varying the depth of burst. The charges in Row H were numbered from the west end. The first four spaces were 20.6 feet, the second four were 25.75 feet, and the third four were 30.9 feet which corresponded to 1.5 single charge crater radii.

A view of the interior of the crater looking west is shown in Figure 3.20. Figure 3.21 shows the cross sections for all three portions of Row H, and Figure 3.22 shows the longitudinal profile. The dimensions of the first and second sections of the crater compared reasonably well with those of Rows C and D. The irregularity of the crater increased with the spacing, as may be clearly seen in Figure 3.23, an aerial view of the crater. The increasing irregularity with increasing spacing is also apparent in the topographic map of the crater in Appendix B (Figure B.3.19). The map also shows the unusual shape of the east end of the crater where the spacing was approximately $1.5 R_a$. It appears that the end charge acted to some extent as an isolated single charge, an effect that was also observed in the Pre-Buggy I Row B crater

Figure 3.20 Interior of Row H crater viewed from the east.

Figure 3.21 Row H crater cross sections.

Figure 3.22 Row H crater longitudinal profiles.

Figure 3.23 Aerial view of Row H crater.

which had the same spacing. The lips of Row H were as regular as the lips associated with the shorter rows. The lip heights, however, were significantly less.

3.2.7 Array F. Because the row charge craters of Pre-Buggy II appeared to be consistently larger than those of the Pre-Buggy I series, four single charges were added to the experimental program to permit a direct comparison with the single charges of Pre-Buggy I. The four charges were arranged as shown in Figure 2.2 with a minimum separation of 170 feet and were fired simultaneously as a matter of operational convenience. They were designated as Array F. Two of the charges, F-1 and F-2, were nitromethane charges identical to the charges used for the rows. The other two, F-3 and F-4, were cast spheres of TNT weighing 950 pounds each. The nitromethane charges were detonated at 19.8 feet, the depth of burst for all Pre-Buggy I rows and all Pre-Buggy II rows except Rows B and C-Prime. The planned Dob for the TNT charges was 18.3 feet; however, Charge F-3 was actually 18.5 feet deep. Figure 3.24 is a vertical aerial view of the four single charge craters. The two NM craters are on the right. The dimensions of the four craters agreed reasonably well - the radii varied from 21.1 to 22.7 feet, with an average of 21.8 feet. The average radius of the two NM craters was slightly larger than that for the two TNT craters. Both NM craters were slightly larger than the two TNT craters. Both NM craters were 11.8 feet deep; the two TNT craters were 10.8 and 11.0 feet deep. However, Pre-Buggy I single charge #4 crater at the same depth-of-burst had a radius of 20.5 feet and a depth of 9.5 feet. Thus, there appears to be a significant difference in the dimensions of the Pre-Buggy I and Pre-Buggy II craters. The average cross sections of the single charge craters are shown in Figure 3.25.

Figure 3.24 Aerial view of Array F craters. Row B crater is also shown.

Comparing the dimensions of the four single charge Pre-Buggy II craters with the cratering curves (Figure 1.2) shows them to be larger than the curves would indicate. The radii of the two nitromethane craters average about 9% larger; those of the two TNT craters average about 10% larger. This is within the scatter of the data to which the curve was fitted. The depths, however, fall far above the curve. The nitromethane craters average 65% too deep and the TNT craters, 37.5%. For this reason, the row charge crater dimensions have been compared with the dimensions of the Pre-Buggy II single charge craters, and not with values indicated by the cratering curves.

Figure 3.25 Typical cross sections of the Array F single charge craters.

The difference in the dimensions of the single charge craters of Pre-Buggy I and Pre-Buggy II has a major effect upon one aspect of the Pre-Buggy II row charge experiments. The spacings used for the Pre-Buggy II row charges were the same as those for Pre-Buggy I, and were intended to correspond to 1.0, 1.125, 1.25, and 1.50 single charge crater radii. Based upon the average of the dimensions of the two nitromethane craters, F-1 and F-2, the spacings, for the 19.8-foot Dob, were:

S	Intended s/R_a	Actual s/R_a
20.6	1.00	0.936
23.2	1.125	1.055
25.75	1.25	1.17
30.9	1.50	1.40

CHAPTER 4

ANALYSIS AND INTERPRETATION

4.1 ROW CRATER DIMENSIONS

4.1.1 Enhancement. To evaluate the effect of charge spacing on the dimensions of row charge craters, the row charge dimensions were compared with the dimensions of a single charge crater at the same depth of burst. The spacing was considered to be a function of the single charge crater radius for purposes of this comparison.

The average widths of the linear portions of the craters from Rows C, G, D, and H were compared with the average diameter of the two nitromethane craters of Array F. Plotting the ratio of row crater widths to single charge crater diameter ($2R_a$) versus row charge spacing divided by the single charge crater radius results in the curve shown in Figure 4.1. If the increase in row charge crater width over single charge crater diameter is considered as an enhancement in width, the parameter $W/2R_a$ may be considered as an "Enhancement Factor for Width," E_w . From

Figure 4.1 Enhancement curve for row charge width.

Figure 4.1 it is seen that at a spacing equal to one single charge crater radius ($s = 1.0 R_a$) the row crater is about 10% wider than

the single charge crater, or $E_w = 1.1$. At a spacing of about $1.27 R_a$ the row crater has approximately the same width as the single charge crater.

If a similar comparison is made between the depth of the single charge crater and the average depth of the linear portion of the row charge craters, the curve of Figure 4.2 results. The

Figure 4.2 Enhancement curve for row charge depth.

trend toward increasing crater dimension with decreasing spacing is more pronounced in crater depth than width. At $S = R_a$ the row crater is approximately 20% deeper than the single charge crater and the row crater depth and single charge crater depth are about equal at $S = 1.22 R_a$. The great enhancement in depth would seem to indicate that the gases produced by the charges are used much more efficiently by the row charge in ejecting material from the true crater than they are by single charges, but the steepness of the slope of the curve would also indicate that this efficiency declines very rapidly as spacing is increased.

4.1.2 Irregularity in Crater Dimensions. The irregularity in the depths and widths of the craters, determined as described in Section 2.3.6, is given in Table 3.1. The irregularity is plotted against spacing in Figure 4.3. Other than the one pronounced

Figure 4.3 Plot of percent irregularities for apparent crater width and depth against charge spacing.

cusps next to the end charge of Row H, and a possible smaller cusp in the first $1.5 R_a$ space of that row; no evidence of cusping was noted in the craters of Pre-Buggy II. There is, however, an increase in irregularity with increasing spacing. The smoothest crater was that produced by Row C.

4.2 LIP DIMENSIONS

4.2.1 Lip Heights. Average lip heights were determined for the uniform portion of each lip, taken as that portion lying between Stations 1.5 and 4.5 for the 5-charge rows and H-1, between Stations 6.5 and 8.5 for H-2, and between Stations 10.5 and 12.5 for H-3. In Table 4.1 are shown comparisons between the row charge side lip heights and the single charge lip heights, and between the side lip heights and crater depths.

As indicated in Table 4.1, the row charge side lip heights average about 2.4 times the height of the single charge crater lips.

TABLE 4.1 LIP HEIGHT COMPARISONS

Row	Spacing (ft)	Dob (ft)	Average Lip Height h_{al} (ft)	Average Single Charge Lip Ht. H_{al} (ft)	Apparent Row Depth d_a (ft)	$\frac{h_{al}}{H_{al}}$	$\frac{h_{al}}{d_a}$	$\frac{\text{Spacing}}{\text{Single CraterRadius}}$
B	20.6	23.0	6.96	-	7.6	-	0.915	-
C	20.6	19.8	6.14	2.67	15.4	2.30	0.399	0.94
C'	20.6	23.0	7.26	-	9.3	-	0.781	-
D	25.8	19.8	7.01	2.67	11.7	2.63	0.599	1.18
G	23.2	19.8	7.06	2.67	13.7	2.64	0.515	1.06
H-1	20.6	19.8	5.78	2.67	14.7	2.16	0.393	0.94
H-2	25.8	19.8	5.80	2.67	13.0	2.17	0.446	1.18
H-3	30.9	19.8	5.51	2.67	10.5	2.06	0.525	1.41

For the Row C crater, the deepest of all the craters, the ratio, average side lip height to average crater depth, was about 0.4, compared to a ratio of 0.25 for the single charge craters. The row craters have higher, more massive lips than the single craters because the ejecta is thrown primarily to the sides of the row and there is no cylindrical divergence. A study of Table 4.1 shows that the lips of the Row H crater were not as high as the lips of the other rows with the same spacings and depths of burst. This is probably due to the fact that the lips of the five-charge rows were not truly uniform. Had they been uniform they would have been spread over a somewhat larger area, resulting in a decrease in average lip height.

An indication of the variation in average lip height with charge spacing and depth of burst for the row charge craters is given in Figures 4.4 and 4.5. In Figure 4.4 the average lip heights (h_{al}) are plotted as a function of the ratio of charge spacing to single charge crater radius for constant depth of burial. In Figure 4.5 the average lip heights are plotted against depth of burst for a constant charge spacing. Neglecting the points for Row H, the lip height appears to increase with charge spacing to a maximum value at $s/R_a \approx 1.1$ and to decrease with further increase in spacing.

Figure 4.4 Variation of row charge side lip height with charge spacing.

The points for Row H do not show a significant variation with spacing over the range of spacings studied. From Figure 4.5, no definite correlation between lip height and spacing can be established; however, the four points available for comparison indicate an increase in lip height with increasing depth of burial.

4.2.2 Irregularity. The relative uniformity of the lip heights is indicated by the percent irregularity values given in Table 3.3. The irregularity averages about 4.7%. The maximum deviation of the highest or lowest measured height for any one lip from the average height of that lip was 36%, but for all lips the average of the deviations was 19%. For comparison, the deviation of the maximum or minimum lip height for a single charge crater

Figure 4.5 Variation of row charge side lip height with depth of burst.

from its average lip height was 70%. Within the range of depths of burst and spacings investigated, the irregularity of the lips does not appear to be a function of either of these parameters.

Comparing the north and south lips of each crater shows that in six of the eight craters the south lip was somewhat higher than the north lip. This apparently anomalous behavior can probably be attributed to the southward slope of the preshot ground surface which caused a somewhat larger portion of the throwout to be deposited on the south side of the crater.

4.2.3 Horizontal Extent of the Lips. A measure of the distance from the centerline of the row craters to the intersection of the lips with the original ground surface was obtained from the transverse sections. This distance is designated r_{eb} . The data

so obtained are tabulated in Table 4.2. It shows that the extent of the lips from the center of the row varies between 3.55 and 4.73 times the radius of a single charge crater of the same yield and depth of burst. From Table 4.2 and Figures 4.6 and 4.7 the effect of varying depth of burst and charge spacing on the horizontal extent of the lips can be seen. Figure 4.6 shows that r_{eb} decreases almost linearly with increasing charge spacing. Although only two

TABLE 4.2 LIP WIDTH COMPARISONS

Row	Spacing Single Crater Radius	Dob	Apparent Crater Width W_a (ft)	Single Crater Radius R_a (ft)	Extent of Lip to Edge r_{eb} (ft)	Distance Between Lip Crests W_{al} (ft)	$\frac{r_{eb}}{R_a}$	$\frac{w_{al}}{W_a}$
B	0.94	23.0	46.2	—	76	65.5	—	1.42
C	0.94	19.8	49.5	22.0	98	70.2	4.45	1.42
C'	0.94	23.0	40.6	—	82	63.0	—	1.55
D	1.18	19.8	46.8	22.0	91	70.2	4.13	1.50
G	1.06	19.8	47.3	22.0	89	68.8	4.05	1.45
H-1	0.94	19.8	49.5	22.0	104	66.1	4.73	1.34
H-2	1.18	19.8	46.7	22.0	92	66.3	4.18	1.42
H-3	1.40	19.8	40.2	22.0	78	59.2	3.55	1.47

Crater	Dob (ft)	Apparent Crater Diameter $2 R_a$ (ft)	Radius R_a (ft)	Distance Between Lip Crests $2 R_{al}$ (ft)	$\frac{2 R_{al}}{2 R_a}$
F-1	19.8	45.4	22.7	54.6	1.20
F-2	19.8	42.4	21.2	56.2	1.33
Average:				55.4	1.27

depths of burst were investigated, an apparently similar behavior of r_{eb} with depth of burst is indicated by Figure 4.7. The effect of increased charge spacing on the extent of the lips is probably caused by the individual charges of the row tending to act more and more independently as the distance between them becomes greater. It would be expected that at some spacing for the depths of burst used, the extent of the lips would be comparable to that for single charge craters, about $3 R_a$. The decrease in the extent of the lips with increasing Dob is probably attributable to the

Figure 4.6 Variation of row charge lip width with charge spacing for constant depth of burst.

Figure 4.7 Variation of row charge lip-width with depth of burst for constant spacing.

narrowing of the trajectory field and the decrease of the initial velocities of the throwout material. The throwout material, having a steeper initial vector and lower initial velocity for the deeper depth of burst, would not be thrown as far.

4.2.4 Lip Crest Distance. The horizontal distance between the lip crests on either side of the row is a function of the lip height and the apparent crater width. This crest-to-crest width increases with increasing crater width and with lip height. For the row craters, the ratio of the distance between the lip crests to the width of the apparent row crater varied between 1.34 and 1.55 and averaged 1.45 (see Table 4.2). For the two single

charge craters at the same depth of burst, the lip crest-to-lip crest diameter divided by the apparent crater diameter averaged 1.27.

4.3 VOLUMES

4.3.1 Row Crater Volumes. An indication of the efficiency with which the charges of a row eject material may be seen from the plot of Figure 4.8. Here the volume of the central or linear portion of the row charge crater divided by the number of charges in that portion of the crater was compared with the average of the volumes of charges F-1 and F-2. It appears that the most efficient spacing in terms of apparent crater volume per charge is about 1.125 single charge crater radii for the depth of burst used. It

Figure 4.8 Enhancement curve for row charge volume.

may be different for other depths of burst. It may also be noted that the volumes of sections H-1 and H-2 of the 13-charge row which compare directly with 5-charge rows C and D, respectively, are smaller than the volumes of the central portion of the 5-charge

rows. This apparently results from the differences in the shape of their cross sections. See Section 4.4.

4.3.2 Lip Volumes. Table 4.3 gives the lip volumes and the apparent crater volumes for the total lip and crater as well as the uniform portion of the crater and lip. Ratios of lip-to-crater volumes also are included in Table 4.3. As may be seen, the total lip volume was greater than the volume of the crater in every case. The volume of the uniform portion of the lip was greater than the volume of the uniform portion of the crater for all of the 5-charge rows; however, for row H the volume of the lip was about the same as the volume of the crater. The volume ratios indicate that it is very likely some bulking of the ejecta and fall-back occurred. It should be pointed out, however, that the volume ratios given in Table 4.3 are not bulking factors since the true crater and lip volumes and the volume of dust deposited beyond the lip must be considered before true bulking factors can be evaluated.

TABLE 4.3 VOLUMES, PRE-BUGGY II

Row	<u>Apparent Crater Volume</u>		<u>Apparent Lip Volume</u>		<u>Lip Volume ÷ Crater Volume</u>	
	Total (ft ³)	Linear Portion (ft ³)	Total (ft ³)	Linear Portion (ft ³)	Total	Linear Portion
B	23,950	14,720	33,820	20,030	1.41	1.36
C	41,420	26,470	50,180	29,240	1.21	1.10
C'	-	14,500	-	18,570	-	1.28
C + C'	71,460	24,171	75,290	-	1.05	-
D	47,775	27,865	59,830	36,020	1.25	1.29
G	43,060	27,400	52,130	30,050	1.21	1.10
H-1	-	26,110	-	28,140	-	1.08
H-2	-	17,860	-	17,630	-	0.99
H-3	-	14,950	-	14,650	-	0.98
H	107,780	-	117,120	-	1.09	-

4.4 ROW CRATER GEOMETRY

It was observed that, in cross section, the shape of the row charge craters is much closer to a hyperbola than to a parabola, the approximation commonly used for single charge craters. Figure 4.9 shows the average cross sections for the three sections of the 13-charge row and Figure 4.10 shows the average cross sections for the 5-charge rows. The average cross section in each case was obtained by (1) measuring the area bounded on the sides by each contour line in the crater and on the ends by lines perpendicular to the line of charges at Stations 1.5 and 4.5, and (2) dividing the area by the distance between the latter two stations (the length of the linear portion of the crater). This determined the average width at each contour line elevation, which was

Figure 4.9 Row H crater average cross sections.

Figure 4.10 Average cross sections for 5-charge craters.

plotted as the half width. In the 13-charge row, because of the location of the transition zones between the sections at differing charge spacings, the linear portions for H-2 and H-3 were taken from Stations 6.5 to 8.5 and from Stations 10.5 to 12.5, respectively.

The hyperbolic cross section and the effect of the charge spacing are strikingly illustrated by Figure 4.9. The straight line portions of the side walls for the three sections of Row H have slopes between 34.2° and 34.5° . This is in the range of values of the natural angle of repose that would be expected for a rounded to subrounded, well-graded granular material (10 and 11). It is reasonable to expect that linear craters in other essentially cohesionless materials will have side slopes near the natural angle of repose of those materials. The curved portion of the cross section – the material deposited in the bottom of the crater – increases in size as the spacing is increased.

The shape of the crater cross sections of the 5-charge row is somewhat more rounded than for the sections of the 13-charge row. (Figure 4.5) The Row C crater has the more nearly parabolic section of the craters at Dob = 19.8 feet, indicating that, at a spacing less than one radius, five charges were not sufficient to obtain a true linear crater. Examination of the topographic maps of the Row B and C craters (Figures B.3.10 and B.3.11) tends to confirm this supposition - most of the contour lines in the crater are somewhat elliptical in shape. In the craters of Rows G and D this effect is less apparent. The somewhat more parabolic cross section of the 5-charge row craters compared with the shape of the sections of Row H explains why the volumes of the sections of the Row H crater are smaller than the linear portions of the corresponding 5-charge row craters.

The crater formed by the detonation of Row D is about 5.5 feet wider and about 5 feet deeper at its east end, at Station 4.5, than at its west end, Station 1.5. The trapezoidal shape of the crater in plan view may be clearly seen in the crater map, Figure B.3.13. This unusual shape apparently results from a gradual decrease in charge depth from west to east resulting from the method of determining specific Dob's for each row of charges (see Section 2.3.2). The final depths of burst were:

Charge #1:	20' 5.5"
Charge #2:	20' 5.0"
Charge #3:	19' 10.5"
Charge #4:	19' 6.5"
Charge #5:	19' 10.0"

This crater would seem to indicate that, at least at a depth of burst near 20 feet or 1,000-pound charges, the dimensions of the row-charge crater are extremely sensitive to slight changes in charge depth.

Three comments should be made on the horizontal shape of the Row H crater. First, the topographic map of the crater (Figure B.3.19), shows the remarkably straight and linear section of the crater at the first five charges at a nominal spacing of one single charge crater radius (actually $s = 0.94 R_a$). Second, the transition section in which the crater rapidly grows narrower and shallower from the one-radius spacing first section to the 1.25-radius spacing middle section is located not at the charge between two sections, #5, but principally about the second charge of the wider spacing, #6, and extends well into the second of the four wider spaces. The second transition occurs in the first space of the third spacing, 1.5 radii, between charges 9 and 10. There also appears to be a slight cusp or saddle between these two charges. The third comment concerns the very pronounced cusp inside of the end charge of the row, #13. This end effect was present in the Row B crater of Pre-Buggy I, also at $1.5 R_a$ spacing, and has been observed in some of the craters produced by charges at moderately wide spacing fired by Vortman at Albuquerque (4).

4.5 OTHER OBSERVATIONS

The directed charge effect of the end charge of Row C-Prime has already been commented upon (Section 3.1.5). The result was to deposit a saddle of material in the bottom and on the sides of the Row C crater. The depth of the Row C crater was decreased by 3.7 feet (i.e., 24% of the original depth) at that point, and its width at about half the original depth (elevation 64 feet) was decreased from 28 to 18 feet. In addition, the north side of the crater shows a slope failure over most of the length of Row C crater which increased its width at the preshot ground elevation by 2.9 feet, but which contributed toward a 2.3% reduction in the volume of the center three-fifths of the crater. Although the total change in the old crater is relatively minor, it could have a

significant effect upon its usefulness as a waterway if intersection of the two craters occurred at a point where the required crater is extremely large (as, for example, in the divide cut of the proposed Isthmian Canal) in which the navigation prism would be near the bottom of the crater.

For extremely large yields, the huge lips along the sides of the row charge crater will add a tremendous additional weight on the areas on either side of the crater that will greatly aggravate the problem of slope stability. Further, the relatively large extent of the area which will be affected by this lip for large yields makes the shape of the ground surface to a considerable distance from ground zero a matter of concern. The location of the row in a narrow valley or on a cross slope steep enough to offset the stabilizing effect of the true lip upthrust would almost certainly result in the complete failure of one or both sides of the crater.

4.6 COMPARISON OF PRE-BUGGY I AND PRE-BUGGY II CRATERS

Reference has been made to the difference in dimensions between the single charge craters of Array F and the crater at a comparable depth of burst in the Pre-Buggy I series. The four row charge craters of Pre-Buggy I also exhibited differences from those of Pre-Buggy II at the same spacings. The row charge crater dimensions are compared in Table 4.4.

Although a detailed investigation of the Pre-Buggy II site was not made, it was located only a few hundred feet to the south of the Pre-Buggy I site, and no differences in soil conditions were noted during the time the experiment was being conducted. The only major difference in procedure between the two series of experiments was the method of stemming the charges employed. In the Pre-Buggy I series a dry sand of the type normally used in general construction work was used for stemming; in Pre-Buggy II

TABLE 4.4 COMPARISON OF DATA - PRE-BUGGY I & II

ROW CRATERS:

Depth of Burial (ft)	Spacing (ft)	Event		Width (ft)			Depth (ft)		
		I	II	I	II	II/I	I	II	II/I
19.8	20.6	A	C	47.0	49.5	1.05	12.9	15.4	1.19
19.8	20.6	A	H-1	47.0	49.5	1.05	12.9	14.7	1.14
19.8	23.2	D	G	43.7	47.3	1.08	7.0	13.7	1.96
19.8	25.8	C	D	39.4	46.8	1.19	4.7	11.7	2.49
19.8	25.8	C	H-2	39.4	46.7	1.19	4.7	13.0	2.77
19.8	30.9	B	H-3	35.5	40.2	1.13	5.2	10.5	2.02

SINGLE CRATERS:

Depth of Burial (ft)	Event	II	Radius (ft)			Depth (ft)		
	I		I	II	II/I	I	II	II/I
19.8	4	F-1	20.5	22.7	1.11	9.5	11.8	1.24
19.8	4	F-2	20.5	21.2	1.03	9.5	9.8 ^a	1.03

^aValue is doubtful. There is a mound in the bottom of the crater.

the native material that had been removed from the emplacement holes during their excavation was used with moisture added. In both cases the stemming was placed in lifts that averaged 18 inches to 2 feet deep and tamped by hand using aluminum rods for Pre-Buggy I and a small hand tamper having a 6-inch-square foot on Pre-Buggy II. In neither case was careful control over the tamping exercised, nor were density measurements made. Subsequent experiments in the same area have shown that the compaction of the alluvial material in that area is very sensitive to moisture content in the range from its natural condition of about 3% to about 14% at which point free water appears and the material becomes unworkable (12). The addition of the water in stemming the Pre-Buggy II charges could have made a major difference in the density and bonding of the stemming. Further, in at least one of the single charges of Pre-Buggy I, the high speed motion picture photography clearly shows a partial stemming failure (8).

4.7 ROW CHARGE CRATER GEOMETRY PREDICTION

The cross sections of the craters to be expected from the detonation of a single charge and from a row of charges of the same yield detonated at the same depth of burst at a spacing of 1.125 single charge crater radii are compared in Figure 4.11. Also shown are the numerical relationships that might be expected for a depth of burst about 6% deeper than optimum. The difference in shape is striking. The row charge crater has almost plane sides whose slope angle is about that of the natural angle of repose of the material. The lips along the sides are 2-1/2 times as high and one-third wider. In none of the row craters produced was there any evidence of an outcrop of the true crater.

Until further row charge experiments have been conducted with larger yields, row crater dimensions and geometry can be predicted from the single charge cratering curves now in use by modifying the dimensions so obtained by the enhancement factors given in Figures 4.1, 4.2, and 4.8, and then determining the lip dimensions by applying the average factors given in Figure 4.11 for h_{al} , w_{al} , and r_{eb} .

From the cross sections of Figures 3.2, 3.6, 3.10, 3.14, 3.18, and 3.21, and the average sections of Figures 4.9 and 4.10, it may be seen that the side slopes are nearly straight for the row charge craters. The average angle of these side slopes is approximately equal to the natural angle of repose of the material, 34 to 35 degrees, and it is to be expected that the side slopes of a row charge crater in any cohesionless material will approach the angle of repose for that material. For saturated cohesionless or for cohesive materials, other mechanisms of formation and failure will govern, and the angle of the side slopes at some time after detonation will be more difficult to predict. Typical values of the angle of repose for rock and granular soils vary between

Figure 4.11 Relationships between average dimensions of row charge and single charge craters.

28 and 40 degrees. This slope angle does not appear as clearly in single charge craters because the approximately circular horizontal section of the crater makes possible a horizontal arching action which permits the slopes to stand at steeper angles. In addition, in single charge craters at near optimum depths of burst, the true crater frequently outcrops into the apparent crater, usually in the upthrust region. Such an outcrop has not been observed in any of the row craters thus far produced, although it may occur at larger yields.

CHAPTER 5

CONCLUSIONS

From the results of the Pre-Buggy II row charge cratering experiments the following conclusions were drawn:

1. At a given depth of burst, increasing the spacing between the charges in a row decreases the width and depth of the crater and increases its irregularity, or departure from linearity. At a depth of burst approximately 16% deeper than optimum for single charge crater radius, when the charges are spaced a distance apart equal to one crater radius, the row is about 10% wider and 20% deeper than the crater produced by a single charge of the same weight buried at the same depth. When the charges are spaced greater than about 1.20 single charge crater radii apart, the dimensions of the cross section of the row approach those of the single charge crater. For the same depth of burst, about 1.16 optimum for radius, the greatest apparent crater volume per charge occurs when the charges are spaced about 1.125 single charge crater radii apart. The charges begin to act independently at a spacing of about 1.5 radii. That is, cusps begin to appear between the charges and the crater becomes quite irregular in shape. If the depth of burst is increased to 1.32 optimum for radius and the spacing held constant at one radius (for the shallower depth of burst), the crater width is reduced by 7% and the depth is reduced by 50%.

2. The shape of the cross section of the row charge crater is not parabolic as has been assumed for the single charge crater, but is more nearly hyperbolic with the slope of the asymptotes approximately equal to the natural angle of repose for noncohesive materials.

3. The lips at the side of the row crater are much higher and more massive than are those around the single charge crater.

The Pre-Buggy II row crater side lips averaged over twice the average lip height of the two single charge craters at the same depth of burst, and were about one-third wider on the average. The lips at the ends of the craters were generally smaller than the average of the single charge crater lips, and were quite irregular in profile, in some places disappearing completely.

APPENDIX A

PRE-BUGGY I DATA

TABLE A.1 PRE-BUGGY I SINGLE CHARGE CRATER DIMENSIONS

Event No.	Hole No.	Dob (ft)	Scaled Dob (ft/kt ^{1/3.4})	R _a (ft)	D _a (ft)	Volume (yd ³)
Test	Test	15.0	140	22.7	10.9	-
1	5	15.0	140	21.0	9.7	243
2	3	16.6	155	21.8	9.1	280
3	1	18.2	170	20.9	7.8	216
4	4	19.8	185	20.6	9.4	242
5	2	21.4	200	19.7 ^a	4.1 ^a	98
6	6	19.6	183	20.7	8.3	225

^aPhotography of Event No. 5 indicates that a partial stemming failure probably occurred.

TABLE A.2 PRE-BUGGY I ROW CHARGE CRATER DIMENSIONS

Event	Row A s = 20.6 ft		Row B s = 30.9 ft		Row C s = 25.8 ft		Row D s = 23.2 ft	
Parameter	w	d	w	d	w	d	w	d
Station	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
1.0	44.6	12.3	35.1	5.1	39.5	4.6	42.5	5.9
1.5	44.8	13.3	33.1	5.5	34.5	4.5	41.0	5.9
2.0	45.3	13.8	37.1	7.7	37.6	4.5	43.5	6.1
2.5	47.1	13.3	33.6	6.2	39.5	5.0	45.0	6.3
3.0	45.5	12.9	35.4	6.9	42.0	4.3	46.3	6.8
3.5	47.0	12.3	33.8	3.7	40.0	4.2	45.5	6.7
4.0	43.2	11.2	32.6	2.5	36.0	4.2	43.0	6.7
4.5	43.1	10.1	28.2	1.8	37.0	4.0	38.5	6.6
5.0	39.9	9.5	29.0	4.3	39.0	4.1	40.2	6.6
Average	44.5	12.1	33.1	4.9	38.6	4.4	42.8	6.4
Average ^a (Station 1.5 to 4.5)	47.0	12.9	35.5	5.22	39.4	4.72	43.7	6.97
Volume	1,300 yd ³		480 yd ³		660 yd ³		905 yd ³	

^aDetermined from maps using planimeter.

APPENDIX B

RAW DATA

B.1 CHARGE DEPTHS AND WEIGHTS

The following table gives the actual hole collar elevations, center of each charge elevation, depth of burial, and actual weight of nitromethane in each charge.

Hole	Collar Elev. (ft)	Center of Charge Elev. (ft)	Depth	NM Weight (lb)
C-1	3172.6	3151.8	20' 10"	1002
C-2	3171.7	3151.8	19' 11-1/2"	995-1/2
C-3	3171.5	3151.6	19' 11"	1000
C-4	3171.5	3151.7	19' 9"	998-3/4
C-5	3170.9	3151.5	19' 5"	998
G-1	3169.4	3149.1	20' 3"	1003-1/2
G-2	3168.8	3148.9	19' 11-3/4"	1007
G-3	3169.2	3148.8	20' 5"	1010-1/4
G-4	3168.7	3148.8	19' 11"	1007
G-5	3168.3	3148.8	19' 6"	1008
D-1	3168.7	3148.2	20' 5-1/2"	999
D-2	3168.6	3148.2	20' 5"	1007
D-3	3168.0	3148.2	19' 10-1/2"	1003-1/2
D-4	3167.8	3148.3	19' 6-1/2"	1002-1/2
D-5	3167.4	3148.3	19' 1"	1000-1/2
B-1	3174.8	3152.0	22' 10"	1003-3/4
B-2	3175.2	3152.0	23' 2-1/2"	999-1/2
B-3	3174.7	3151.7	22' 11-3/4"	1001-1/2
B-4	3174.7	3151.8	22' 11"	997-1/4
B-5	3174.8	3151.8	22' 11-1/2"	999-1/4

Hole	Collar Elev. (ft)	Center of Charge Elev. (ft)	Depth	NM Weight (lb)
C-Prime-6	3172.4	3149.5	22' 10"	1008
C-Prime-7	3173.5	3149.5	24'	1003-1/2
C-Prime-8	3172.7	3149.6	23' 1-1/4"	1006
C-Prime-9	3172.3	3149.4	22' 10"	1007-1/2
C-Prime-10	3172.4	3149.5	22' 10"	997-1/4
H-1	3166.4	3146.7	19' 8"	990
H-2	3166.2	3146.4	19' 10"	997-1/2
H-3	3166.2	3146.3	19' 11"	999-1/4
H-4	3166.2	3146.4	19' 9"	999-3/4
H-5	3166.3	3146.4	19' 11"	996
H-6	3166.2	3146.3	19' 11"	985-3/4
H-7	3166.6	3145.7	20' 11"	998
H-8	3166.6	3146.3	20' 4"	997-1/2
H-9	3165.9	3144.9	21'	997-1/4
H-10	3165.5	3144.9	20' 7"	993-3/4
H-11	3164.0	3143.0	19'	1008
H-12	3164.9	3144.9	20'	992
H-13	3164.2	3144.8	19' 5"	987-1/2
F-1	3172.8	3152.7	20' 1"	988
F-2	3172.7	3152.7	20'	986-1/2
F-3	3176.2	3155.7	18' 6"	950 ^a
F-4	3173.9	3155.6	18' 4"	950 ^a

^aF-3 and F-4 have 950-pound cast TNT spheres as explosive charges.

The spacing of individual charges in the rows was as planned ± 0.25 feet.

B.2 METEOROLOGICAL DATA

The following is the meteorological data recorded by U. S. Weather Bureau at a mobile station in Area 5.

Event - Row C

Time and date - 1230 PDT - May 28, 1963

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
surface	215/10		
250	215/10		
500	215/10		
750	208/9	None Taken	None Taken
1000	210/11		
1250	205/11		
1500	202/12		
2000	191/10		

Event - Row G

Time and Date - 1400 PDT - June 5, 1963

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
surface	190/15	892	27.8
100	191/17	889	26.9
200	193/16	885	25.7
276	194/16	882	24.6
300	195/16	881	24.5
400	196/14	879	24.1
500	196/16	876	23.6
750	199/17	868	22.4

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
1000	203/19	860	21.1
1500	206/20	845	19.7
2000	207/21	830	18.4
2500	207/20	815	17.1
3000	207/21	802	15.8
4000	204/18	774	13.0
5000	200/16	745	10.0

Event - Row D

Time and Date - 1215 PDT - June 7, 1963

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
surface	280/08	901	21.4
100	282/08	897	20.0
200	285/07	893	19.4
300	287/07	890	18.2
400	289/06	888	17.6
500	293/05	884	17.0
750	301/03	878	16.1
1000	299/04	870	15.9
1500	288/06	856	15.0
2000	278/05	839	13.5
2500	254/04	824	12.0
3000	184/04	809	10.6
4000	261/03	780	7.8
5000	000/00	753	5.1

Event - Row B

Time and Date - 1200 PDT - June 11, 1963

No data available - not enough helium to loft meteorological balloon.

Event - Row C-Prime

Time and Date - 1443 PDT - June 13, 1963

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
surface	190/10	900	27.8
100	190/10	899	27.5
200	190/10	896	26.4
300	189/10	891	24.2
400	189/10	885	23.1
500	189/10	884	23.0
750	187/11	879	22.8
1000	185/11	869	21.8
1500	182/12	854	20.5
2000	181/12	839	19.0
3000	178/12	810	16.2
4000	160/11	782	13.3
5000	160/13	754	10.3

Event - Row H

Time and Date - 1325 PDT - August 2, 1963

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
surface	200/08	902.8	35.1
100	200/08	900	34.0

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (°C)
200	195/09	894	31.0
300	190/10	892	30.2
400	187/10	890	30.1
500	183/10	887	29.9
750	175/15	880	29.3
1000	174/14	872	28.6
1500	174/13	857	27.2
2000	170/11	843	26.0
2500	164/11	829	24.8
3000	165/12	816	23.4
4000	168/15	787	20.2
5000	170/13	759	17.2

Event - Array F

Time and Date - 1530 PDT - August 6, 1963

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (°C)
surface	123/08	905	33.1
100	124/08	902	31.6
200	129/09	899	30.6
300	131/11	896	29.5
400	134/13	893	28.8
500	139/13	890	28.7
750	138/10	882	28.3
1000	141/08	873	27.9
1500	150/08	857	26.3
2000	153/11	845	25.2
2500	171/08	829	23.8

Height (above ground surface) (ft)	Wind (deg/kt)	Pressure (mb)	Temp (° C)
3000	184/13	815	22.3
4000	192/16	788	19.7
5000	228/12	760	16.6

B.3 TOPOGRAPHIC MAPS

Figure B.3.1 Preshot topographic map, Row B.

Figure B.3.2 Preshot topographic map; Row C/C-Prime.

Compiled By:
American Aerial Surveys, Inc.
364 S. Stewart Dr.
Carlsbad, California
Date: 5-13-63
Datum: Based On Sea Level 1929
Contour Interval: 2'

SCALE
20 0 20 40
FEET

AREA 5
PROJECT Pre-BUGGY PHASE II
PRE-TEST TOPOGRAPHY

HOLMES & HARVEY, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.3 Preshot topographic map, Row D.

Compiled By
American Aerial Surveys, Inc.
564 S. Stewart Dr.
Covina, California
Date: June 5-13-63
Data Based On: Sanborn 1929
Contour Interval: 2'

AREA 5
PROJECT Pre-BUGGY PHASE II
PRE-TEST TOPOGRAPHY
HOLMES & HARVEY, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.4 Preshot topographic map, F-1.

Compiled By
American Aerial Surveys, Inc.
3645 Stewart Dr.
Corona, California
Date: March 5-13-63
Datum Based On Sea Level 1929
Contour Interval 2'

AREA 5
PROJECT Pre-BUGGY PHASE II
PRE-TEST TOPOGRAPHY

HOLMES & HARVER, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.6. Preshot topographic map, F-3.

AREA 5
PROJECT PRE-BUGGY PHASE II
PRE-TEST TOPOGRAPHY
HOLMES & HARRIS, INC.
ENGINEERS-CONSTRUCTORS

Contract No. 100-100-100
American Road & Builders Builders, Inc.
2445 Shuman Dr.
Suite 100
New York, N.Y. 10001
Date: March 1, 1983
Drawn: March 1, 1983
Checked: March 1, 1983
Reviewed: March 1, 1983

Figure B.3.9 Preshot topographic map, Row H.

115-116

Compiled By
American Aeronautic Surveys, Inc.
3648 Stewart Dr.
Orvine California
Data From 6-11-63
Datum Based On Sea Level 1929
Contour Interval 1'

AREA 5
PROJECT Pre-BUGGY PHASE II
POST-TEST TOPOGRAPHY

HOLMES & NARVER, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.13 Postshot topographic map, Row D.

Compiled By
American Aerial Surveys, Inc.
584 S. Stewart Dr.
Carls, California
Date: June 8 - 12 - 63
Datum Based On Sea Level 1929
Contour Interval 1'

Pre BUGGY PHASE II
ARRAY F PORTION OF AREA 5
POST TEST TOPOGRAPHY

HOLMES & HARVEY, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.14 Postshot topographic map, F-1.

Compiled By
American Solid Surveys, Inc.
564 S. Stewart Dr.
Corona, California
Date Plotted 8-12-83
Datum Based On Sea Level 1929
Contour Interval 1'

Pre BUGGY PHASE II
ARRAY PORTION OF AREA 5
POST TEST TOPOGRAPHY

HOLMES & HARVER, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.15 Postshot topographic map, F-2.

Compiled By
 Simpson & Sons, Inc.
 301 S. Stewart St.
 Carson, California
 Date: June 12 - 63
 Datum: Based On Sea Level 1929
 Contour Interval: 1'

Pre BUGGY PHASE II
 ARRAY F PORTION OF AREA 5
 POST TEST TOPOGRAPHY

HOLMES & HARVEY, INC.
 ENGINEERS-CONSTRUCTORS
 LAS VEGAS, NEVADA

Figure B.3.16 Postshot topographic map, F-3.

Compiled By
American Aerial Surveys, Inc.
584 S. Stewart Dr.
Covina, California
Data From 8-12-63
Drum Read On Site April 1969
Contour Interval

Pre BUGGY PHASE II
ARRAY PORTION OF AREA 5
POST TEST TOPOGRAPHY

HOLMES & HARVEY, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.17 Postshot topographic map, F-4.

Compiled by
American Aerial Surveys, Inc.
584 S. Stewart St.
Carina, California
Dolls Placer 6-8-63
Datum Based On Sea Level 1929
Contour Interval

AREA 5
PROJECT Pre-BUGGY PHASE II
POST-TEST TOPOGRAPHY
HOLMES & HARVEY, INC.
ENGINEERS-CONSTRUCTORS
LAS VEGAS, NEVADA

Figure B.3.18 Postshot topographic map, Row G.

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 1111 14th Street, N.W.
 Washington, D.C. 20005
 Phone: (202) 462-1000
 Fax: (202) 462-1001

FIGURE B.3.19
 AREA 5
 POST TEST TOPOGRAPHY
 SURVEY & MAPS, INC.
 1001 14th Street, N.W.
 Washington, D.C. 20005

Figure B.3.19 Postshot topographic map, Row H.

APPENDIX C

SCIENTIFIC PHOTOGRAPHY COVERAGE

Scientific photography of the Pre-Buggy II experiments was planned and carried out by the LRL/Nevada Photography Group. It was planned to record surface motion, base surge, and cloud formation, and to document each event from -3 seconds to +15 minutes, using two ground camera stations and one aerial camera station located in an orbiting H-21 helicopter at an altitude 1500 feet above the ground surface. Camera stations were designated as follows:

<u>Station</u>	<u>Location</u>
#1	1700 feet south of surface zero
#2	2000 feet west of surface zero
#3 (Helicopter)	Airborne orbit - 1000 feet radius at 4670 feet.

Figure C.1 shows the location of camera stations, and Table C.1 gives the cameras, fields of view, run times, and other pertinent information.

From Station #1, two high speed cameras were used to photograph the motion of an array of flares (FF 33 Flash Flood) set up in a line along the line of charges (Figures C.2 and C.3). The flares were lighted 1/2 second before zero time, and burned for a total of 2-3/4 seconds. The camera lens was stopped down so that only the pinpoints of light from the flares showed on the film. Timing marks were also recorded on the edge of the film to accurately establish the time sequence. From the film record so obtained, the velocity and configuration of the ground surface in its displacement over each charge array could be accurately determined. Figure C.4 shows a schematic wiring diagram for the camera stations and flares. A fiducial flash bulb was installed near the center of the charge array and wired so as to be activated by the CDU when the charges were fired to mark zero time on the film.

Figure C.1 Location of camera stations.

As indicated in Table C.1, cameras at both ground stations and in the helicopter were used to record the formation, growth, and dissipation of the cloud and base surge. To provide a scale on the ground for estimation of the base surge diameter and shape on the film, an array of large base surge targets were set up as shown in Figure C.5. The design of the targets is also shown.

TABLE C.1 SCIENTIFIC PHOTOGRAPHY COVERAGE

Camera	PPS	Run Time	Lens Focal Length	Field of View Width X Height		Film	Purpose
<u>Station #1</u> , wooden building 1700 ft south of surface zero							
1. Photo Sonics	1000	16 sec	50 mm	245	X 328	400' X 16 mm B & W	Earth motion & flare
2. Photo Sonics	1000	16 sec	100 mm	122	X 164	400' X 16 mm B & W	Earth motion & flare
3. Photo Sonics	50	5 min 20 sec	13 mm	962	X 1312	400' X 16 mm Color	Base surge & cloud formation
<u>Station #2</u> , wooden building 200 ft west of surface zero							
4. Bell & Howell	64	1 min	50 mm	289	X 386	100' X 16 mm Color	Earth motion
5. Photo Sonics	50	5 min 20 sec	13 mm	1153	X 1546	400' X 16 mm Color	Base surge & cloud formation
<u>Station #3</u> , H-21 helicopter 1500 ft over surface zero							
6. Arriflex	48	+15 min	Variable	Variable		400' X 16 mm Color	Earth motion, base surge & cloud formation

Figure C.2 Surface motion flare stand.

Figure C.3 Location of flares.

Figure C.4 Wiring diagram.

Figure C.5 Layout and construction of base surge targets.

APPENDIX D
MAGNETIC EJECTA STUDIES
RAW DATA

On the last portion of the experiment, Row H and Array F, a study of the ejecta was made using magnets. Bar magnets, three inches long by one-half inch in diameter, were coated by dipping in a melted plastic to reduce their density to approximately that of the alluvium. They were placed on lines along the surface and buried at varying depths along the sides of the emplacement holes in the stemming material as it was placed.

Three of the thirteen holes of Row H were used. Of the 38 magnets emplaced, 30 were recovered postshot, 7 were located but not recovered, and 1 was lost.

Two of the four holes of Array F were used. Of the 61 magnets emplaced, 40 were recovered postshot, 8 were located but not recovered, and 13 were lost.

The area was surveyed postshot with a Varian M-49 magnetometer to locate those magnets not found visually. This system seems quite satisfactory at the scale of this experiment. Tables D.1 through D.3 and Figures D.1 through D.3 give the preshot and postshot location of the magnets used in the experiment.

TABLE D.1 PRESOT MAGNET LOCATIONS - EVENT F-2

Single Charge F-2

Magnet Number and Depth

Down Hole Magnets	South Side of Hole	1B 17' 0"	26B 15' 0"	23B 11' 0"	25B 8' 6"	9B 7' 0"	3B 5' 3"	4B 3' 0"	5B Top
	North Side of Hole	42S	3S-30S 14' 10" West Side	49S 11' 1"	40S 8' 6"	9S 7' 2"	31S 5' 0"	45S 3' 0"	1S Top

Surface Magnets

Figure D.1 Magnet recovery positions - Event F-2.

TABLE D.2 PRESLOT MAGNET LOCATIONS - EVENT F-3

Single Charge F-3

		Magnet Number and Depth						
Down Hole Magnets	South Side of Hole	27B 18' 0"	21B 14' 6" West Side	7B 11' 0"	17B 7' 6"	47B 5' 0"	16B 3' 9"	10B Top
	North Side of Hole	16S 18' 0"	26S 15' 6"	38S 11' 0"	37S 7' 0"	6S 6' 0"	33S 3' 9"	27S Top

Surface Magnets

Figure D.2 Magnet recovery positions - Event F-3.

TABLE D.3 PRESLOT MAGNET LOCATIONS - ROW H

Magnet Number & Depth								
Hole #1	South Side of Hole	# unknown 16' 4"	44B 12' 6"	49B 11' 0"	31B 8' 8"	4S 6' 0"	29S 2' 6"	
	North Side of Hole	20S 16' 2"	13S 12' 4"	46S 11' 1"	39S 8' 6"	32S 6' 2"	44S 2' 6"	
Hole #3	South Side of Hole	46B 15' 4"	36B 14' 0"	47B 10' 4"	42B 5' 8"	40B 4' 6"	37B 2' 0"	
	North Side of Hole	15S 15' 6"	7S 13' 0"	11S 10' 4"	6S 5' 9"	14S 3' 9"	2S 2' 0"	
Hole #5	South Side of Hole	45B 13' 0"	34B 12' 5"	48B 10' 6"	43B 9' 0"	39B 6' 6"	41B 5' 0"	32B 2' 6"
	North Side of Hole	25S 14' 6"	17S 12' 5"	10S 10' 7"	19S 9' 2"	21S 6' 6"	23S 5' 2"	12S 2' 6"

Figure D.3 Magnet recovery positions - Row H.

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