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TID-4500 (50th Ed.)
NUCLEAR EXPLOSIONS--
PEACEFUL APPLICATIONS

PLOWSHARE

COMPARISON OF CRATERS FROM ROWS OF CHARGES DETONATED SIMULTANEOUSLY AND ONE AT A TIME

L. J. Vortman, 7111

November 1967

SANDIA LABORATORIES

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ABSTRACT

Row charges made up of 64-pound spherical TNT charges were detonated in one instance simultaneously and in the other instance one-at-a-time in sequence for combinations of two spacings and three burial depths. Where the charges were detonated one at a time, the crater volume was reduced to nearly 50 percent of the volume for the comparable simultaneous detonation. There was not much difference for the combinations of burial depth and spacing tested. The craters from one-at-a-time detonations averaged about 35 percent larger for the greater spacing than for the smaller spacing versus only about 10 percent difference when the charges were fired simultaneously.

jb

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ACKNOWLEDGMENT

Field work for the experiment described herein was directed by J. R. Cejka and V. A. Harris. Arming and firing was done by W. E. Holder. Topographic mapping was accomplished by Limbaugh Engineers, Inc., under direction of W. J. Harron. The work was supported by the Atomic Energy Commission, Division of Peaceful Nuclear Explosives, as a contribution to the Plowshare Program.

COMPARISON OF CRATERS FROM ROWS OF CHARGES DETONATED SIMULTANEOUSLY AND ONE AT A TIME

Introduction and Summary

In large scale nuclear excavations such as a second transisthmian canal, it may not be possible because of safety considerations to achieve the benefits of simultaneously detonating rows of charges. If the charges are fired only one at a time, what is the penalty in terms of degradation of crater dimensions? Does the degradation vary with burial depth and spacing?

To answer these questions, pairs of row charges identical in burial depth and spacing were fired simultaneously in one case and one at a time in the other. Rows of seven 64-pound spherical TNT charges were used. Charge spacings of 6 and 8 feet, and charge burial depths of 5, 6, and 7 feet at those spacings were used.

Crater widths were slightly smaller for the one-at-a-time detonations. Average crater depths were also smaller and by a larger percentage than width. Scaled crater volumes for one-at-a-time detonations were reduced by nearly 50 percent on an average below those for simultaneous detonations.

If one-at-a-time detonations are to be used, the larger spacing is better than the smaller spacing because less ejecta is dispersed by being directed preferentially by early venting in the direction of the pre-existing portion of the crater.

Background

The potential use of nuclear explosives for such excavations as a sea level interoceanic canal contemplates rows of explosives divided into sections, each section being detonated simultaneously. The length of each section would be predicated on the maximum permissible single-salvo yield allowed by safety criteria established for the site under consideration. Where elevations are high, the yield of each explosion in the row will be large. As a result, the row must be short if the single-salvo yield is to remain within the established allowable--possibly only a single charge can be fired.

Early work[1,2] has shown that the full advantage of simultaneously-detonated row charges is not developed if less than 6 or 7 charges are in the row.

Another effort[3] examined the crater from short rows (1, 2, 3, or 5 charges) and their interaction with craters from a nearly comparable number of charges. The results did not exhibit the same reduction in cratering effectiveness for short rows. More recently,[4] the possibility of firing charges one at a time (nibbling) to better accommodate blast and seismic safety criteria was examined, using charges in a wide horizontal array followed by a row beneath the resulting crater. Because of backfill from subsequent detonations, the nibbling technique resulted in nearly a 50 percent reduction in crater volume from that of a single charge. These results indicated that it was in order to explore in a more systematic manner the degradation of cratering effectiveness resulting from firing charges one at a time rather than simultaneously--the objective of the work described herein.

Experiment Plan

Spherical TNT charges weighing 64 pounds were used because they were available. Each row consisted of seven charges. Since row charges ordinarily would be employed over a range of charge burial depths and spacings, it was important to examine a range of both parameters.

Tables I and II show the combinations of spacing and burial depth which were used for simultaneous and one-at-a-time detonations, respectively. The intent was to fire one simultaneous and one non-simultaneous shot for each combination of burial depth and spacing, but as a result of misunderstanding in the field, no non-simultaneous shot was fired at a depth of 5 feet and spacing of 8 feet. Instead, two shots were fired simultaneously at a depth of 7 feet and spacing of 8 feet.

TABLE I

Spacing and Burial Depth
of Simultaneous Detonations

Burial depth (ft)	Spacing (ft) 6	Spacing (ft) 8
5	Shot 3, Figure 3	Shot 1, Figure 1
6	Shot 4, Figure 4	*
7	Shot 11, Figure 6	Shots 2 and 5, Figures 2, 5

*Data supplied by a crater from an earlier experiment in which the spacing was 9 feet.[5]

TABLE II

Spacing and Burial Depth of
One At A Time Detonations

Burial depth (ft)	Spacing (ft) 6	Spacing (ft) 8
5	Shot 10, Figures 23-26	Not fired
6	Shot 9, Figures 19-22	Shot 6, Figures 7-10
7	Shot 8, Figures 15-18	Shot 7, Figures 11-14

Crater contour mapping was accomplished by aerial mapping methods, using an aerial stereo camera with a modified focal length to accommodate photographs from a platform suspended from a crane boom rather than photography from an aircraft. The non-simultaneous shots were photographed after each of the seven charges were fired and mapping was done to show craters after detonation of shots 1, 3, 5, and 7. Crater dimensions were determined for each of the craters mapped.

Results

Crater dimensions are summarized in Table III.

Crater Width

For simultaneous detonations, there is a clear increase in crater width with deeper burial depth. Where the spacing is larger the crater width is consistently smaller.

For charges detonated one at a time, there was no trend with charge spacing. There is some suggestion of a wider crater with increased charge burial depth.

Crater widths for one-at-a-time detonations averaged only 83 percent of widths for simultaneous detonations. The difference was greatest for combinations of 7-foot burial depth and 6-foot spacing.

TABLE III

Summary of Crater Dimensions

		One-At-A-Time					Simultaneous Detonation				
		Width (ft)	Depth (ft) (Av)	Depth (ft) (Max)	Volume (ft^3)	Scaled Volume (ft^3/lb)	Width (ft)	Depth (ft) (Av)	Depth (ft) (Max)	Volume (ft^3)	Scaled Volume (ft^3/lb)
6 ft Spacing:											
		Shot 10					Shot 3				
5 ft DOB	1	15.94		4.90	404.84	6.33					
	3	15.36	4.24	5.56	811.75	4.23					
	5	16.20	3.67	5.12	1196.82	3.74					
	7	16.28	3.34	5.10	1495.80	3.34	19.70	5.38	5.94	2743.69	6.12
		Shot 9					Shot 4				
6 ft DOB	1	16.82		4.25	410.97	6.42					
	3	17.00	4.53	5.65	819.93	4.27					
	5	16.79	3.57	5.14	1207.05	3.77					
	7	16.77	3.28	5.10	1522.32	3.40	19.84	5.28	5.92	2724.05	6.08
		Shot 8					Shot 11				
7 ft DOB	1	16.72		3.97	513.40	8.02					
	3	17.15	4.27	4.88	915.56	4.77					
	5	16.65	3.65	5.20	1262.26	3.94					
	7	16.50	3.27	5.04	1556.15	3.47	21.04	5.44	6.16	3322.89	7.42
8 ft Spacing:											
							Shot 1				
5 ft DOB	1	Not fired									
	3										
	5										
	7						18.29†	4.53	5.32	2808.37	6.27
		Shot 6									
6 ft DOB	1	15.96		3.94	354.44	5.54					
	3	16.35	4.23	5.21	1036.64	5.40					
	5	16.37	3.75	5.38	1610.26	5.03					
	7	16.19	3.35	5.00	2035.80	4.54	19.26	5.03	6.00	3583.85	8.00
		Shot 7					Shots 2 and 5				
7 ft DOB	1	15.42		3.21	317.84	4.97					
	3	15.78	3.98	5.43	965.50	5.03					
	5	16.72	3.87	5.90	1588.66	4.96					
	7	16.84	3.49	6.03	2088.76	4.66	20.12	5.37	5.79	3760.47	8.39
							19.70	4.59	5.38	3158.23	7.05

†Dimensions from an earlier shot with a spacing of 9 feet (Ref. 5).

Crater Depth

Average depths for simultaneous shots were smaller for the larger spacing. There was no trend with burial depth. There was no trend with either spacing or burial depth for non-simultaneous detonations.

Both the average crater depth (averaged between end charges) and the maximum crater depth are recorded in Table III. Maximum crater depth for non-simultaneous detonation is misleading, since the crater is always deepest at the location of the last charge fired. Similarly, average crater depth of non-simultaneous shots is exaggerated since it is increased by the contribution of the last charge. Thus if a crater were formed by a non-simultaneous detonation of a larger number of charges, the average depth would be less than found here. If there were fewer charges, the average depth would be more because of the relatively greater contribution of the last charge.

For non-simultaneous charges average depth was about the same for all spacings and burial depths. Maximum depth was about the same for all spacings and for all burial depths except that the 8-foot spacing and 7-foot DOB was about 20 percent larger than the others.

Average crater depths for non-simultaneous detonations were only 64 percent of those for simultaneous detonations on the average. Maximum crater depths for non-simultaneous detonations averaged only 89 percent of those for simultaneous detonations. The average was increased by the fact that for the 8-foot spacing and 7-foot burial depth, the maximum crater depth for the non-simultaneous detonation was greater than that for simultaneous detonation.

Crater Volume

For simultaneous detonations, the volumes were always greater for the larger spacing. While there was no consistent trend with burial depth, an increase in volume with increased burial depth from 5 to 7 feet is suggested.

Crater volume was always greater for the simultaneous detonations than for the non-simultaneous shots. Where charges were fired one at a time, there was a consistent increase in volume with increase in spacing or burial depth. Volumes for 8-foot spacing were significantly larger than for 6-foot spacing.

On an average of five shots of each type, the non-simultaneous craters were only 55 percent as large as the simultaneous shots. For three simultaneous and non-simultaneous shots of 6-foot burial depth, the comparable value is 52 percent; for two shots of each type at 8-foot burial depth, it is 59 percent.

Discussion

The crater resulting from the first charge in the one-at-a-time series can be compared with craters from other single charges in the same medium.[6] All dimensions were generally larger than those of craters from comparable earlier explosions. All prior data suggested the peak of the volume depth-of-burst curve should be between 5 and 6 feet. These data are insufficient to warrant a change in the single-charge optimum burial depth from the 5.4 feet (for a 64-pound charge) noted in Reference 2.

Reference 2 also noted that the optimum crater from simultaneously detonating charges in a row occurred at a burial depth 10 percent greater than the optimum single charge burial depth for one of the charges in the row for charge spacings which made a channel uniformly wide and deep. This is comparable to the 6-foot burial used for some of the rows described here.

For simultaneous explosions Reference 2 had shown that for a 6-foot burial depth the maximum spacing which would give a crater uniformly deep, with maximum efficiency in explosive use, was about 8 feet. This observation was behind a choice of 8 feet as one of the spacings to be examined. It was anticipated that firing the charges one at a time would result in smaller crater dimensions. A 6-foot spacing was added on the assumption that closer spacing of charges (greater energy density per unit length) would recover some of the loss. For reasons given later, it now appears it would have been better to have examined a spacing larger than 8 feet rather than smaller. When the spacing between charges was 6 feet, none of the crater dimensions were clearly maximized at the 6-foot burial depth. When the spacing between charges was 8 feet, the maximum for width occurs for a 7-foot burial depth, average depths are about the same as 6- and 7-foot burial depths, and the volume for two 7-foot deep shots averages only slightly smaller than for the 6-foot deep shot. All simultaneous shots meet the criteria for a channel uniformly wide and deep. These shots verify the criteria for line-charge crater equivalence laid down in Figures 4.4 and 4.5 of Reference 2.

Where the charges were detonated one-at-a-time,* the 6-foot burial depth showed a slight maximum in crater width but volume and depth were about the same for all three burial depths. There were only 6- and 7-foot deep shots with an 8-foot spacing. The average crater width for the 7-foot shot was greater than for the 6-foot shot; depth and volume were about the same for both burial depths. The volume for both non-simultaneous shots with the 8-foot spacing was about 35 percent greater than for the two comparable shots with the 6-foot spacing, even though all shots with one-at-a-time firing had less volume than comparable shots with simultaneous detonations. The 35 percent difference compares with only about a 10 percent difference for simultaneous detonations. Thus, although there is a disadvantage in cratering efficiency when charges are fired one at a time, in those instances where it is necessary to reduce seismic and airblast safety problems, it is better to use the larger spacing. These results suggests that spacings even larger than 8 feet may further reduce the disadvantage of one-at-a-time detonations.

An interesting aspect of the differences in scaled volume between one-at-a-time detonation of rows with 6- and 8-foot spacing is seen in the progressive change in scaled crater volume as successive charges are detonated. This is illustrated in Figure 1. The single charges produce large craters; then because of backfill, each additional detonation reduces the scaled volume, but by a decreasing amount. For the series of two rows with spacing between charges of 8 feet the single charge craters were smaller than for the series of three rows where the spacing was 6 feet for reasons not understood.

---

*Figures 7 through 26 show crater profiles and topographic maps for the charges fired one-at-a-time. Crater profiles for simultaneous detonations with the same charge burial depth and spacing have been added for comparison to Figures 11 through 26.

(Single charge craters, of course, should be the same regardless of spacing of charges to be detonated subsequently.) Subsequent detonations, however, reduce the scaled volume by smaller amounts than for a smaller charge spacing. This is in part because the ejecta at a given charge location decreases as the spacing increases. More importantly, it is because at the closer spacing the explosion vents preferentially toward the pre-existing crater, thus causing more to be deposited along the axis of the pre-existing crater than in other directions, and more than in the case of the larger spacing. This is consistent with other investigations.[3] As a result, the possibility of a still larger spacing than 8 feet producing a more optimum crater from one-at-a-time detonation may exist. An optimum crater may occur where the spacing is just large enough that there is no venting into an adjacent pre-existing crater before venting occurs over the charge. Where venting occurs over the charge, ejecta should be distributed with nearly circular symmetry and there would be little or no additional ejecta in the direction of an adjacent pre-existing crater.

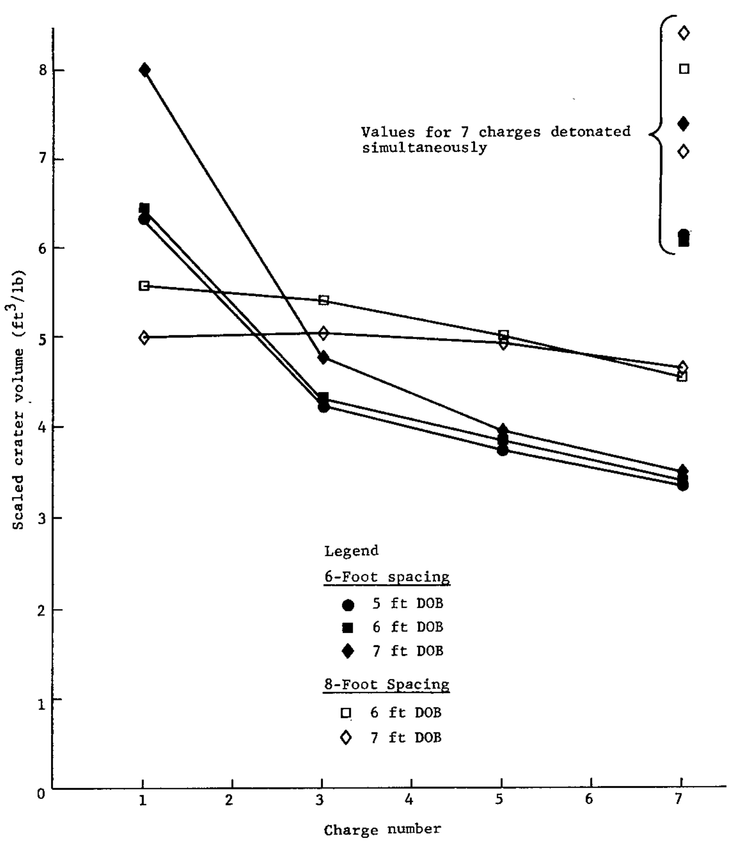

Figure 1. Change in scaled crater volume as additional charges are detonated

Conclusions

When charges in a row are detonated one-at-a-time rather than simultaneously, nearly a 50 percent reduction in crater volume occurs. Differences in reduction between the combinations of spacing and burial depth examined were small. The results suggested that where charges are fired one-at-a-time it is better to use a spacing which does not permit or which reduces preferential venting and ejecta distribution down the axis of the pre-existing crater. Consequently, spacings larger than those examined here should be explored.

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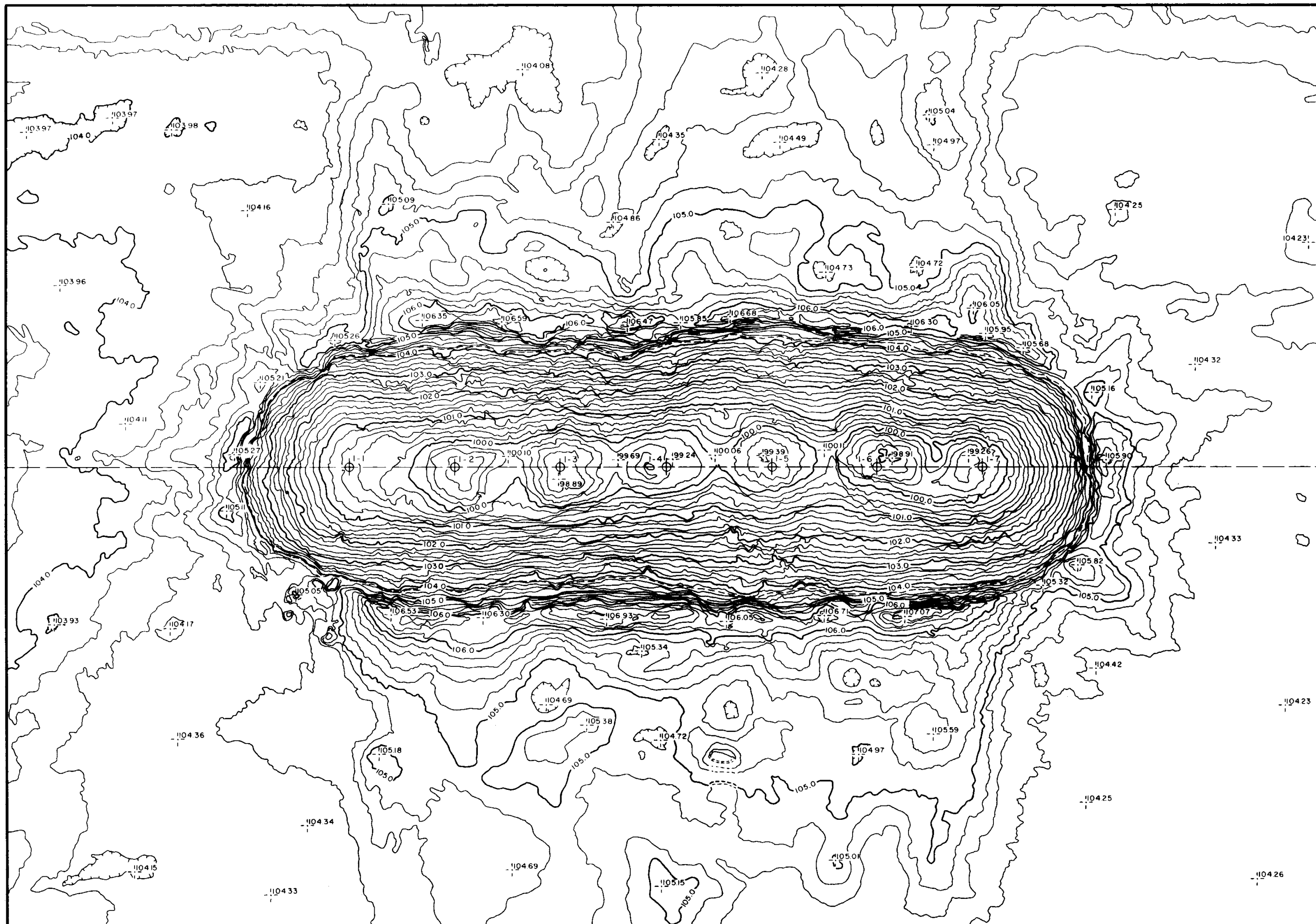
4. Vortman, L. J., Craters From an Individually Detonated Multiple-Charge Array, SC-RR-67-727, Sandia Laboratory, Albuquerque, New Mexico, 1967.

5. Vortman, L. J. Craters from Row Charges Interrupted By a Dud, SC-RR-67-3, Sandia Laboratory, Albuquerque, New Mexico, February, 1967.

6. Deitz, J. P. and Hayes, D. B., Compilation of Crater Data, SC-RR-65-220, Sandia Laboratory, Albuquerque, New Mexico, July, 1965.

APPENDIX

Topographic Maps



POST SHOT PAD No. 1

NOVEMBER 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
2808.37 cu. ft.

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 1-1	3.58'
# 1-2	4.79'
# 1-3	5.25'
# 1-4	4.49'
# 1-5	4.83'
# 1-6	5.08'
# 1-7	4.87'

DEEPEST POINT IN CRATER
5.32'

HIGHEST POINT ON LIP
2.68'

AVERAGE CRATER DEPTH BETWEEN END CHARGES
4.53'

AVERAGE CRATER WIDTH BASED ON INTERCEPT AREA BETWEEN END CHARGES
1-1 - 1-7 18.29'

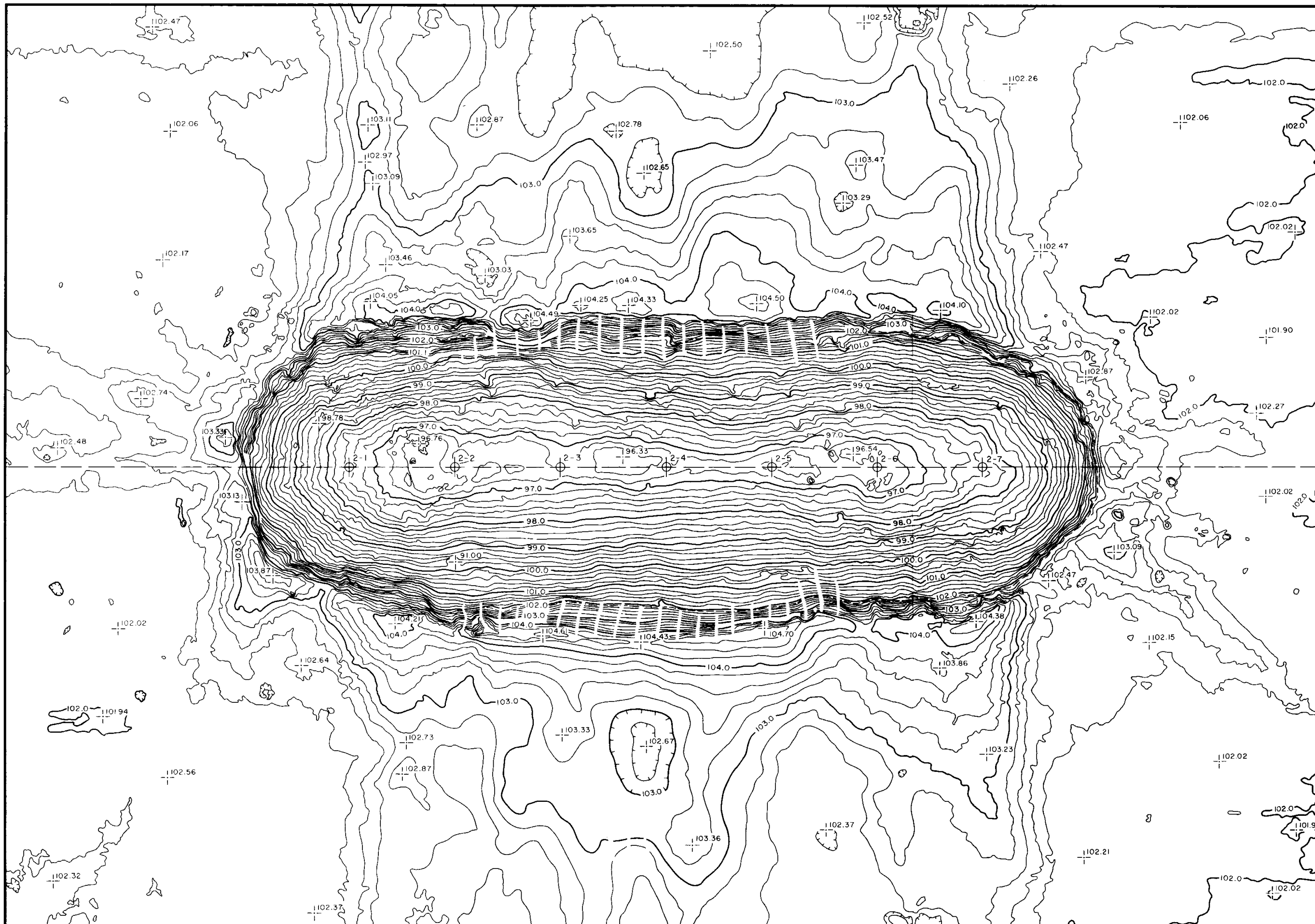
LEGEND

CHARGE LOCATION (FIRED) ⌖
INTERCEPT - - - - -
PROFILE LINE — —

CRATER FORMED BY
SIMULTANEOUS DETONATION OF
7-64 lb. CHARGES- 8ft. SPACING - 5ft. DEEP

LIMBAUGH ENGINEERS, INC.
CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

Figure 1



POST SHOT PAD No. 2

NOVEMBER 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
3760.47 cu. ft.

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 2-1	4.71'
# 2-2	5.51'
# 2-3	5.37'
# 2-4	5.53'
# 2-5	5.50'
# 2-6	5.46'
# 2-7	4.54'

DEEPEST POINT IN CRATER
5.79'

HIGHEST POINT ON LIP
2.76'

AVERAGE CRATER DEPTH BETWEEN END CHARGES
5.37'

AVERAGE CRATER WIDTH BASED ON INTERCEPT AREA BETWEEN END CHARGES
2-1 - 2-7 20.12'

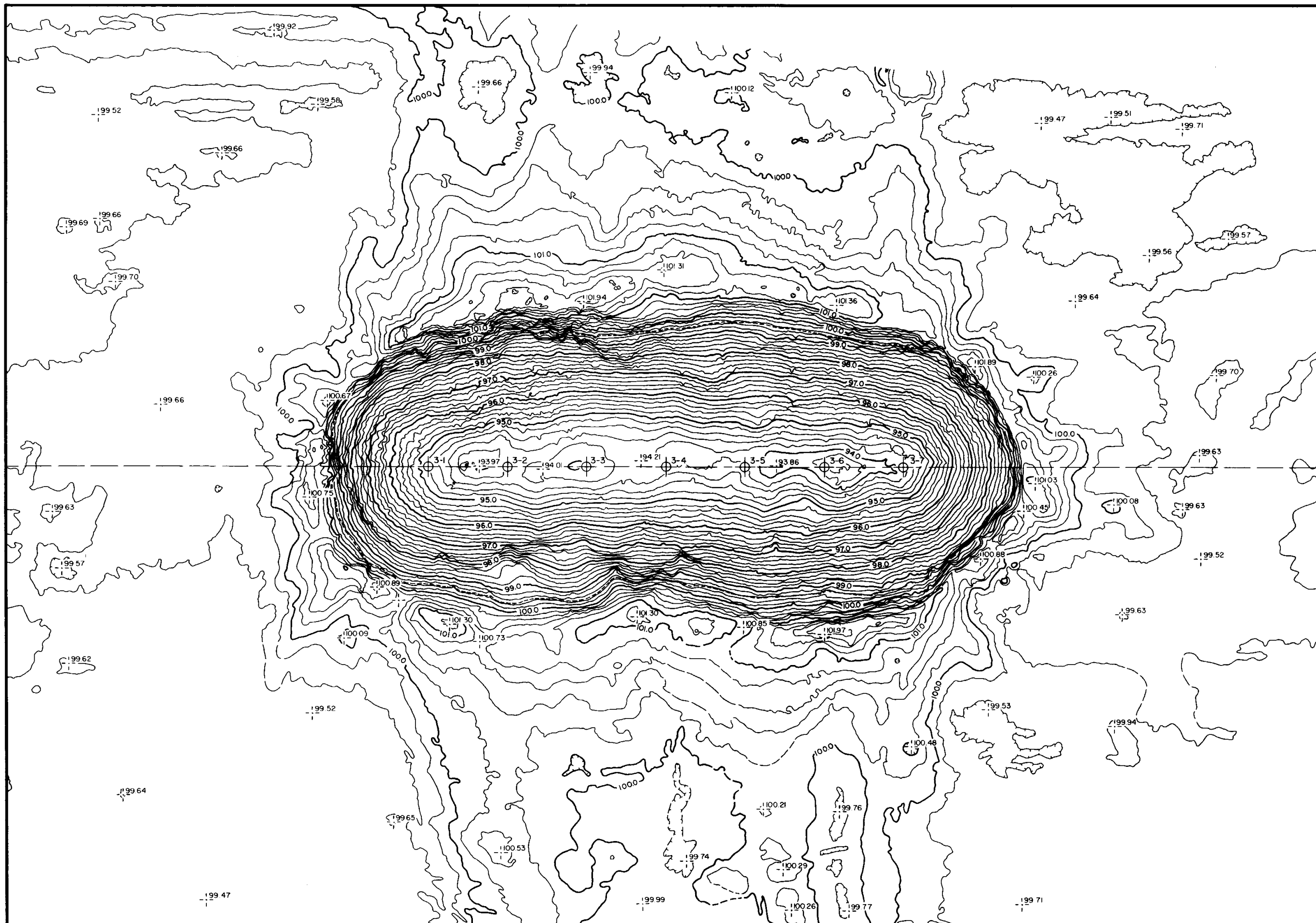
CRATER FORMED BY
SIMULTANEOUS DETONATION OF
7-64 lb. CHARGES-8 ft. SPACING -7 ft. DEEP

LEGEND

CHARGE LOCATION (FIRED) ⊕
INTERCEPT - - - - -
PROFILE LINE — —

LIMBAUGH ENGINEERS, INC.
CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

Figure 2



POST SHOT PAD No. 3

NOVEMBER 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
2743.69 cu. ft.

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 3-1	4.79'
# 3-2	5.20'
# 3-3	5.51'
# 3-4	5.29'
# 3-5	5.30'
# 3-6	5.79'
# 3-7	5.09'

DEEPEST POINT IN CRATER
5.94'

HIGHEST POINT ON LIP
2.67'

AVERAGE CRATER DEPTH BETWEEN END CHARGES
5.38'

AVERAGE CRATER WIDTH BASED ON INTERCEPT AREA BETWEEN END CHARGES
3-1 - 3-7 19.70'

CRATER FORMED BY
SIMULTANEOUS DETONATION OF
7-64 lb. CHARGES-6 ft. SPACING -5 ft. DEEP

LEGEND

CHARGE LOCATION (FIRED) ⊕
INTERCEPT - - - - -
PROFILE LINE — —

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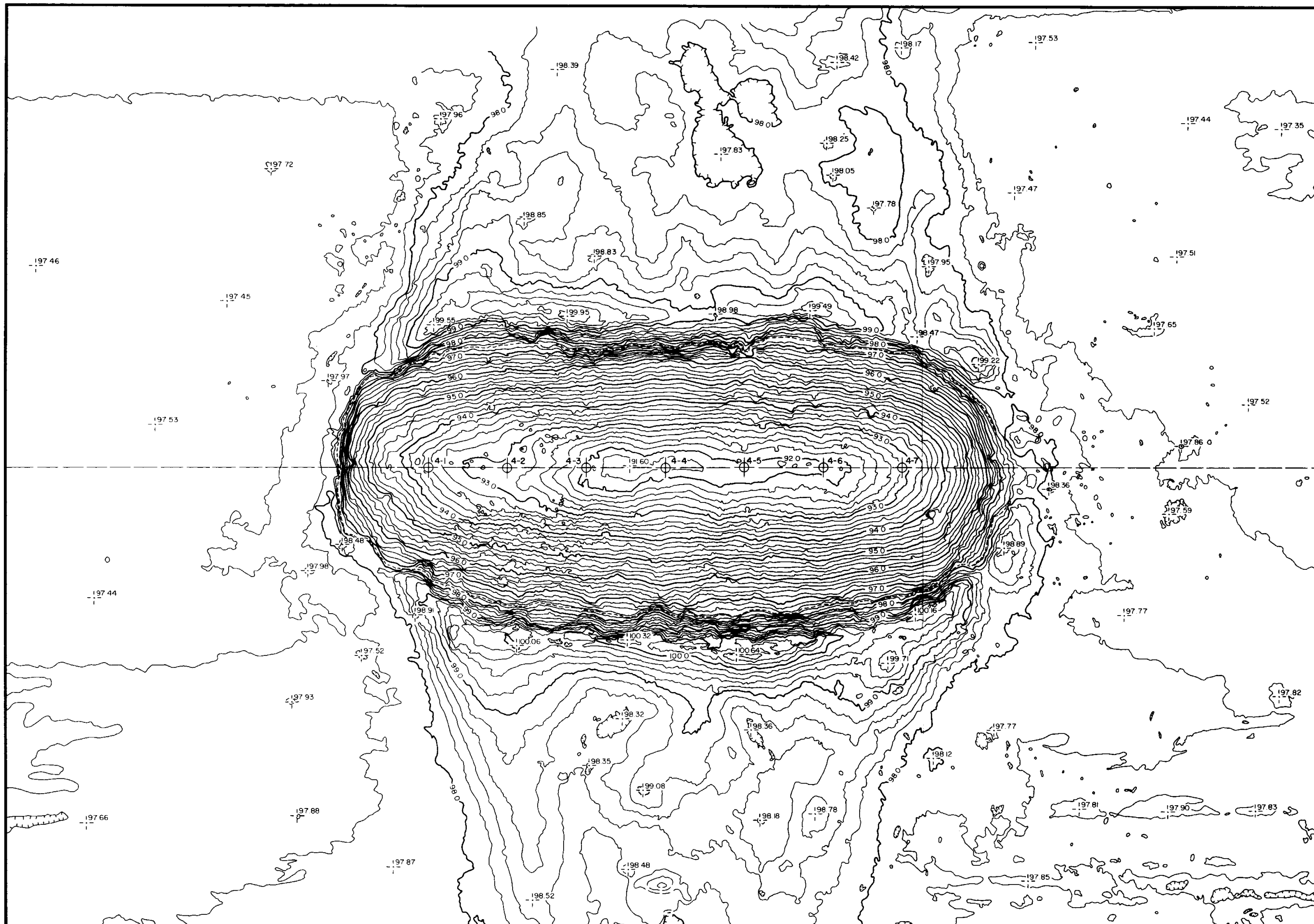
Figure 3



POST SHOT PAD No. 4

NOVEMBER 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
2724.05 cu. ft.

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 4-1	4.04'
# 4-2	4.60'
# 4-3	5.61'
# 4-4	5.73'
# 4-5	5.66'
# 4-6	5.55'
# 4-7	4.74'

DEEPEST POINT IN CRATER
5.92'

HIGHEST POINT ON LIP
3.17'

AVERAGE CRATER DEPTH BETWEEN END CHARGES
5.28'

AVERAGE CRATER WIDTH BASED ON INTERCEPT AREA BETWEEN END CHARGES
4-1 - 4-7 19.84'

CRATER FORMED BY
SIMULTANEOUS DETONATION OF
7-64 lb. CHARGES-6 ft. SPACING - 6 ft. DEEP

LEGEND

CHARGE LOCATION (FIRED)
INTERCEPT
PROFILE LINE

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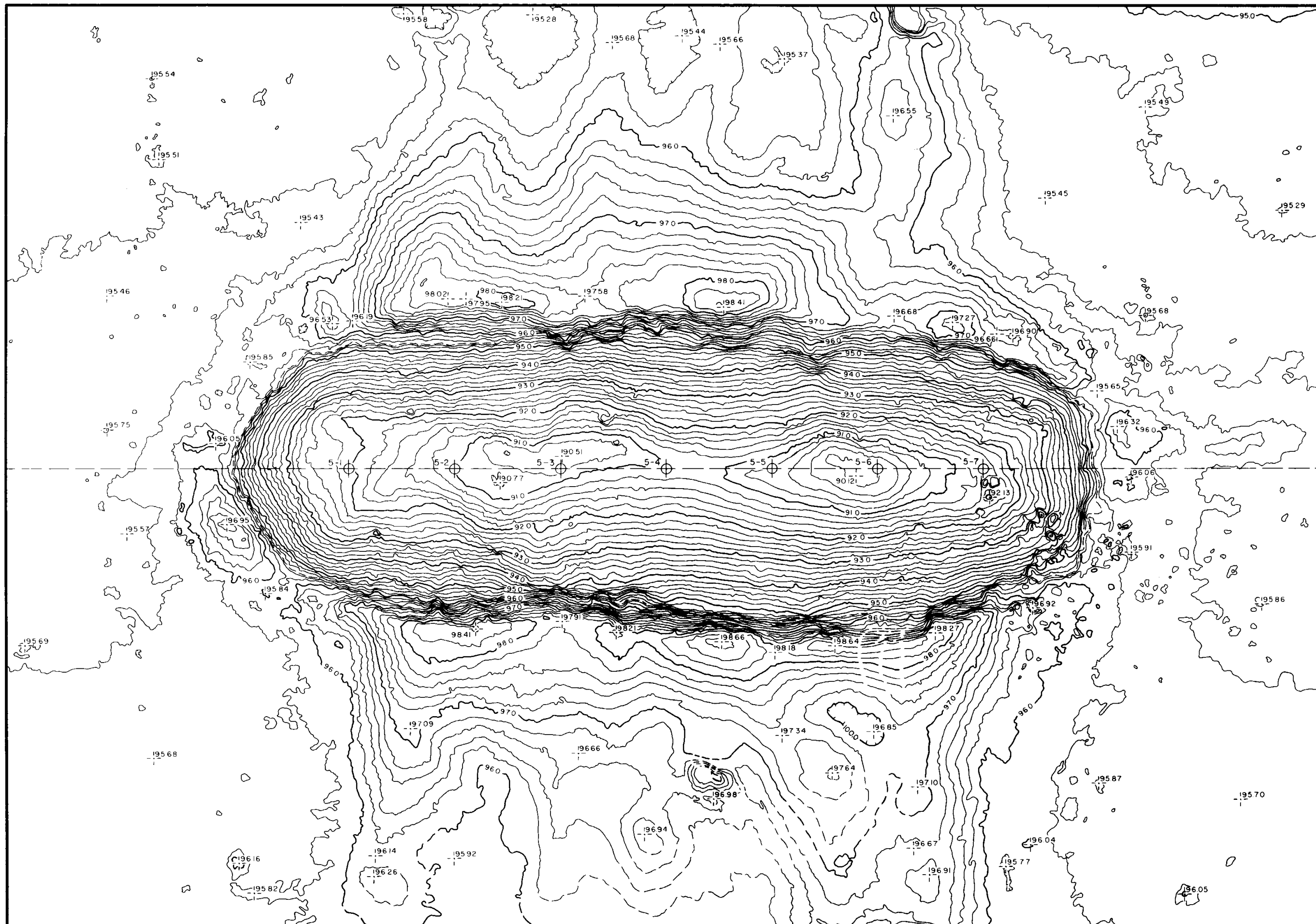
Figure 4



POST SHOT PAD No. 5

NOVEMBER 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
3158.23 cu. ft.

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 5-1	3.58'
# 5-2	4.68'
# 5-3	4.85'
# 5-4	4.49'
# 5-5	4.78'
# 5-6	5.19'
# 5-7	4.13'

DEEPEST POINT IN CRATER
5.38'

HIGHEST POINT ON LIP
3.14'

AVERAGE CRATER DEPTH BETWEEN END CHARGES
4.59'

AVERAGE CRATER WIDTH BASED ON INTERCEPT AREA BETWEEN END CHARGES
5-1 - 5-7 19.70'

CRATER FORMED BY
SIMULTANEOUS DETONATION OF
7-64 lb. CHARGES-8 ft. SPACING - 7 ft. DEEP

LEGEND

CHARGE LOCATION (FIRED)
INTERCEPT
PROFILE LINE

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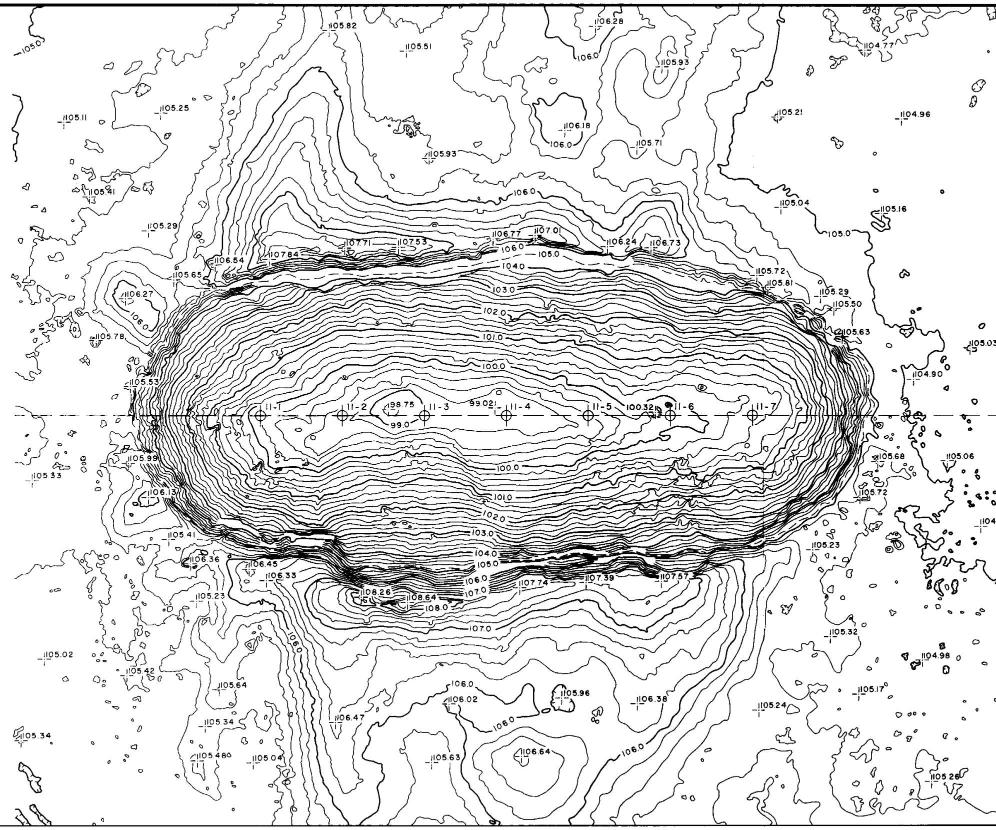
Figure 5



CRATER FORMED BY
SIMULTANEOUS DETONATION OF
7-64 lb. CHARGES - 6 ft. SPACING - 7 ft. DEEP

POST SHOT PAD No. 11

OCTOBER 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
3,322.89 cu. ft.

DEPTHS BELOW ORIGINAL GROUND ZERO

Charges	Depths	Charges	Depths
11-1	5.26'	11-5	5.53'
11-2	5.66'	11-6	5.02'
11-3	5.79'	11-7	4.60'
11-4	5.76'		

DEEPEST POINT IN CRATER
6.16'

HIGHEST POINT ON LIP
3.80'

AVERAGE CRATER DEPTH BETWEEN END CHARGES
5.44'

AVERAGE CRATER WIDTH BASED ON
INTERCEPT AREA BETWEEN END CHARGES
11-1 - 11-7 21.04'

LEGEND

CHARGE LOCATIONS (FIRED) ⊕
INTERCEPT - - - - -
PROFILE LINE — —

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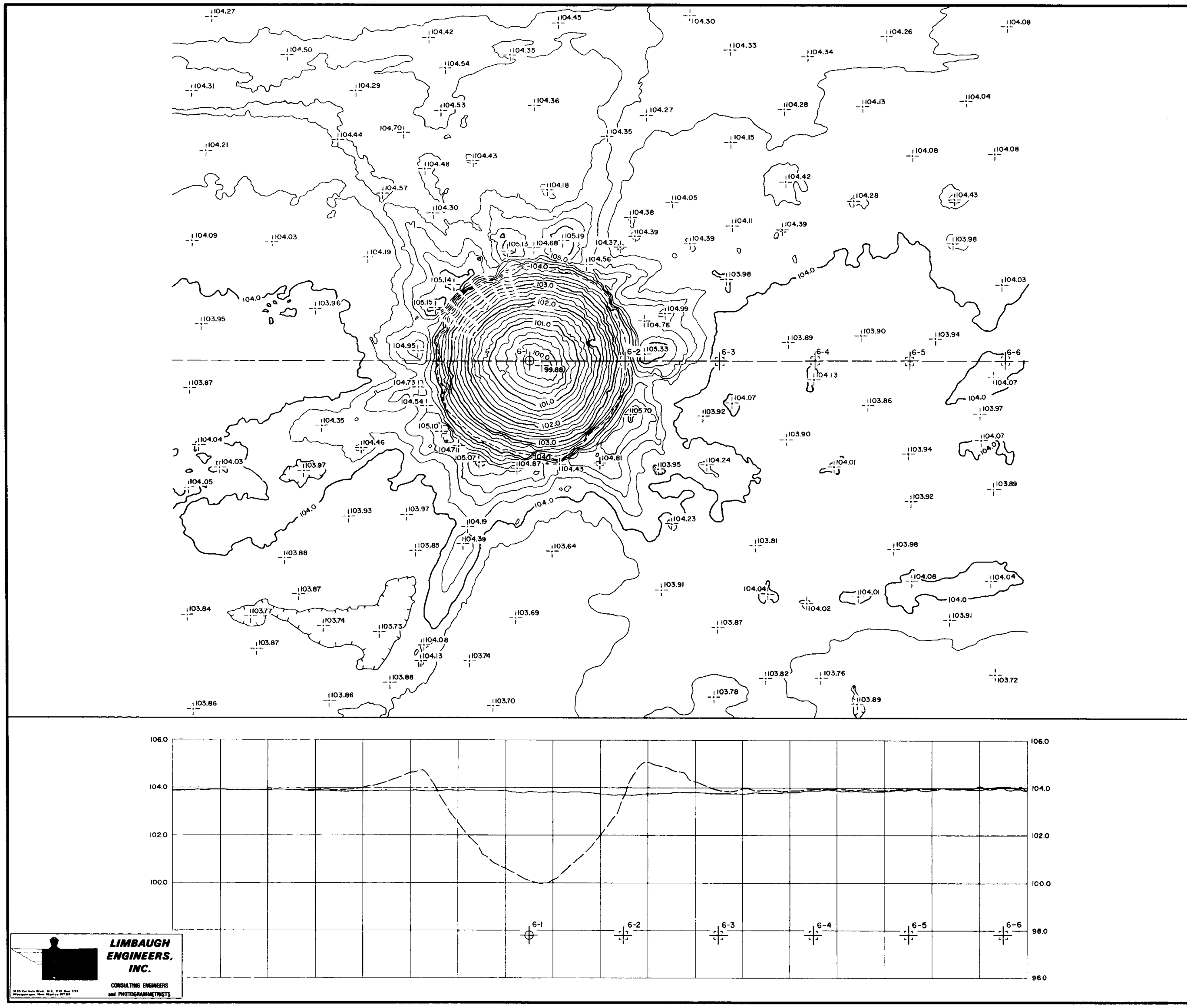
CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

Figure 6



CRATER FORMED BY SEQUENTIAL FIRING OF SINGLE 64 lb. CHARGES - 8 ft. SPACING - 6 ft. DEEP

POST SHOT CHARGE No. 6-1

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
354.44 cu.ft.

RADIUS OF CIRCLE OF EQUIVALENT AREA
7.98'

DEPTHS BELOW ORIGINAL GROUND ZERO
Charge
6-1 3.70'

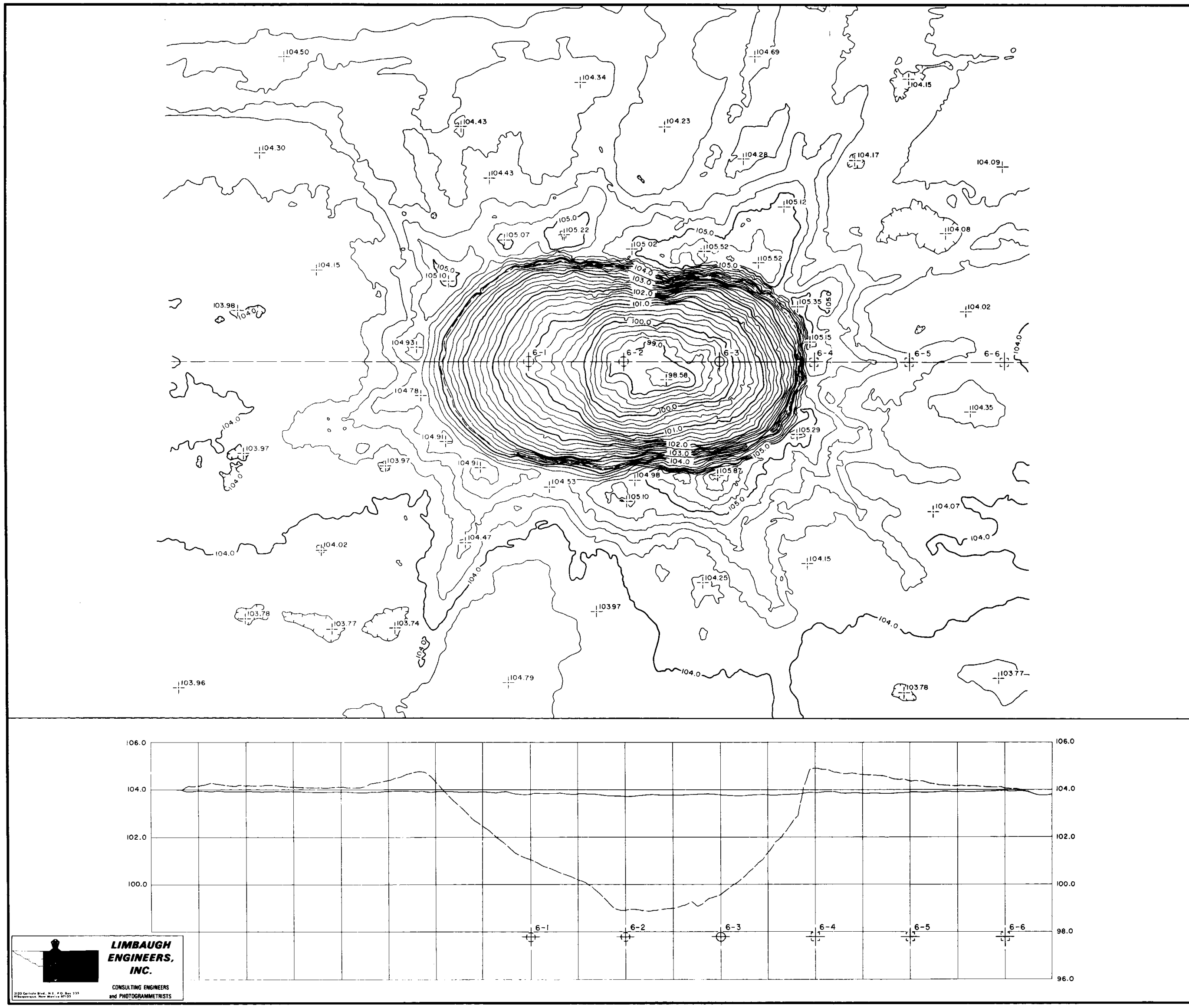
DEEPEST POINT IN CRATER
3.94'

HIGHEST POINT ON LIP
1.93'

LEGEND

- CHARGE LOCATION (FIRED)
- CHARGE LOCATIONS (TO BE FIRED)
- INTERCEPT
- PROFILE LINE
- ORIGINAL GROUND SURFACE
- POST SHOT NO. 6-1

Figure 7



CRATER FORMED BY SEQUENTIAL FIRING

OF

SINGLE 64 lb. CHARGES

8 ft. SPACING - 6 ft. DEEP

POST SHOT CHARGE No.6-3

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME

1036.64 cu.ft.

AVERAGE CRATER DEPTH

4.23'

AVERAGE CRATER WIDTH

16.35'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 6-1	2.81'
# 6-2	4.82'
# 6-3	4.22'

DEEPEST POINT IN CRATER

5.21'

HIGHEST POINT ON LIP

2.07'

LEGEND

CHARGE LOCATION (FIRED)

CHARGE LOCATION (PREVIOUSLY FIRED)

CHARGE LOCATIONS (TO BE FIRED)

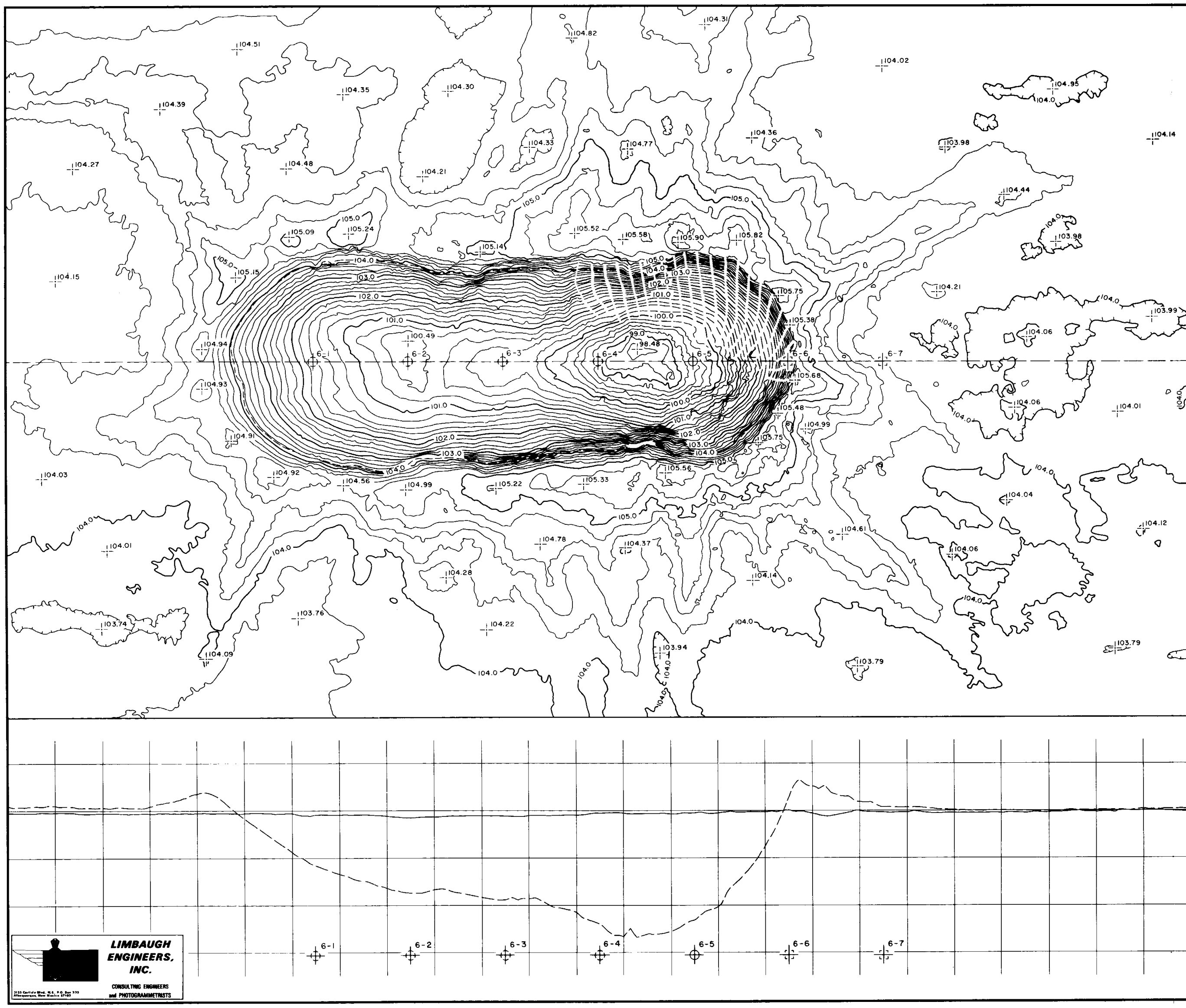
INTERCEPT

PROFILE LINE

ORIGINAL GROUND SURFACE

POST SHOT NO. 6-3

Figure 8



CRATER FORMED BY SEQUENTIAL FIRING

OF

SINGLE 64 lb. CHARGES

8 ft. SPACING - 6 ft. DEEP

POST SHOT CHARGE No. 6-5

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME

1610.26 cu.ft.

AVERAGE CRATER DEPTH

3.75'

AVERAGE CRATER WIDTH

16.37'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 6-1	2.19'
# 6-2	3.21'
# 6-3	3.54'
# 6-4	4.72'
# 6-5	4.53'

DEEPEST POINT IN CRATER

5.38'

HIGHEST POINT ON LIP

2.12'

LEGEND

CHARGE LOCATION (FIRED)

CHARGE LOCATION (PREVIOUSLY FIRED)

CHARGE LOCATIONS (TO BE FIRED)

INTERCEPT

PROFILE LINE

ORIGINAL GROUND SURFACE

POST SHOT NO. 6-5

Figure 9

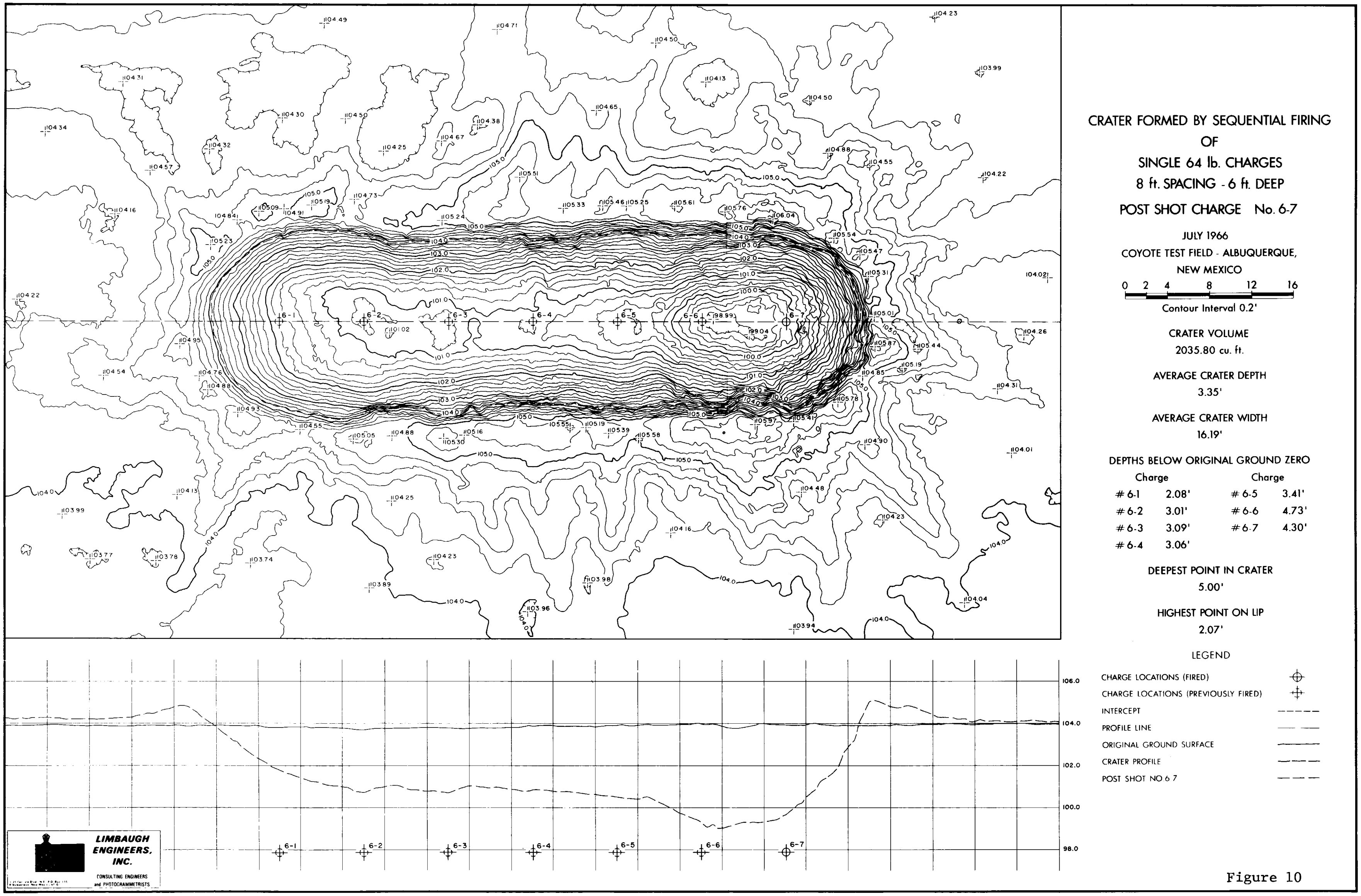
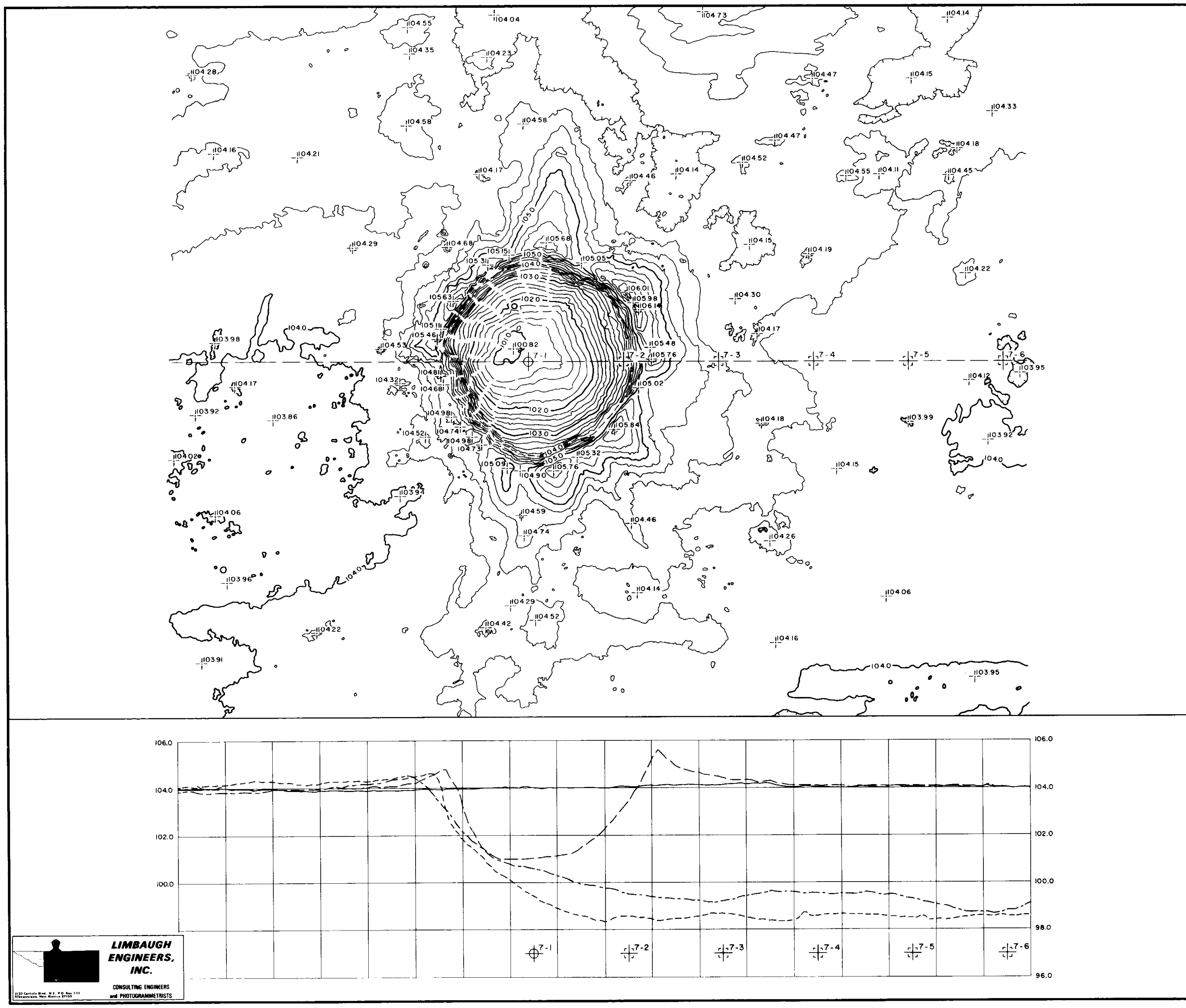

CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
8 ft. SPACING - 6 ft. DEEP
POST SHOT CHARGE No. 6-7
JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO
0 2 4 8 12 16
Contour Interval 0.2'
CRATER VOLUME
2035.80 cu. ft.
AVERAGE CRATER DEPTH
3.35'
AVERAGE CRATER WIDTH
16.19'
DEPTHS BELOW ORIGINAL GROUND ZERO
Charge
6-1 2.08'
6-2 3.01'
6-3 3.09'
6-4 3.06'
Charge
6-5 3.41'
6-6 4.73'
6-7 4.30'
DEEPEST POINT IN CRATER
5.00'
HIGHEST POINT ON LIP
2.07'
LEGEND
CHARGE LOCATIONS (FIRED)
CHARGE LOCATIONS (PREVIOUSLY FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
CRATER PROFILE
POST SHOT NO 6 7
106.0
104.0
102.0
100.0
98.0
6-1
6-2
6-3
6-4
6-5
6-6
6-7
LIMBAUGH ENGINEERS, INC.
CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

Figure 10



CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
8 ft. SPACING - 7 ft. DEEP
POST SHOT CHARGE No. 7-1

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
317.84 cu. ft.

RADIUS OF CIRCLE OF EQUIVALENT AREA
7.71'

DEPTHS BELOW ORIGINAL GROUND ZERO
Charge
7-1 2.96'

DEEPEST POINT IN CRATER
3.21'

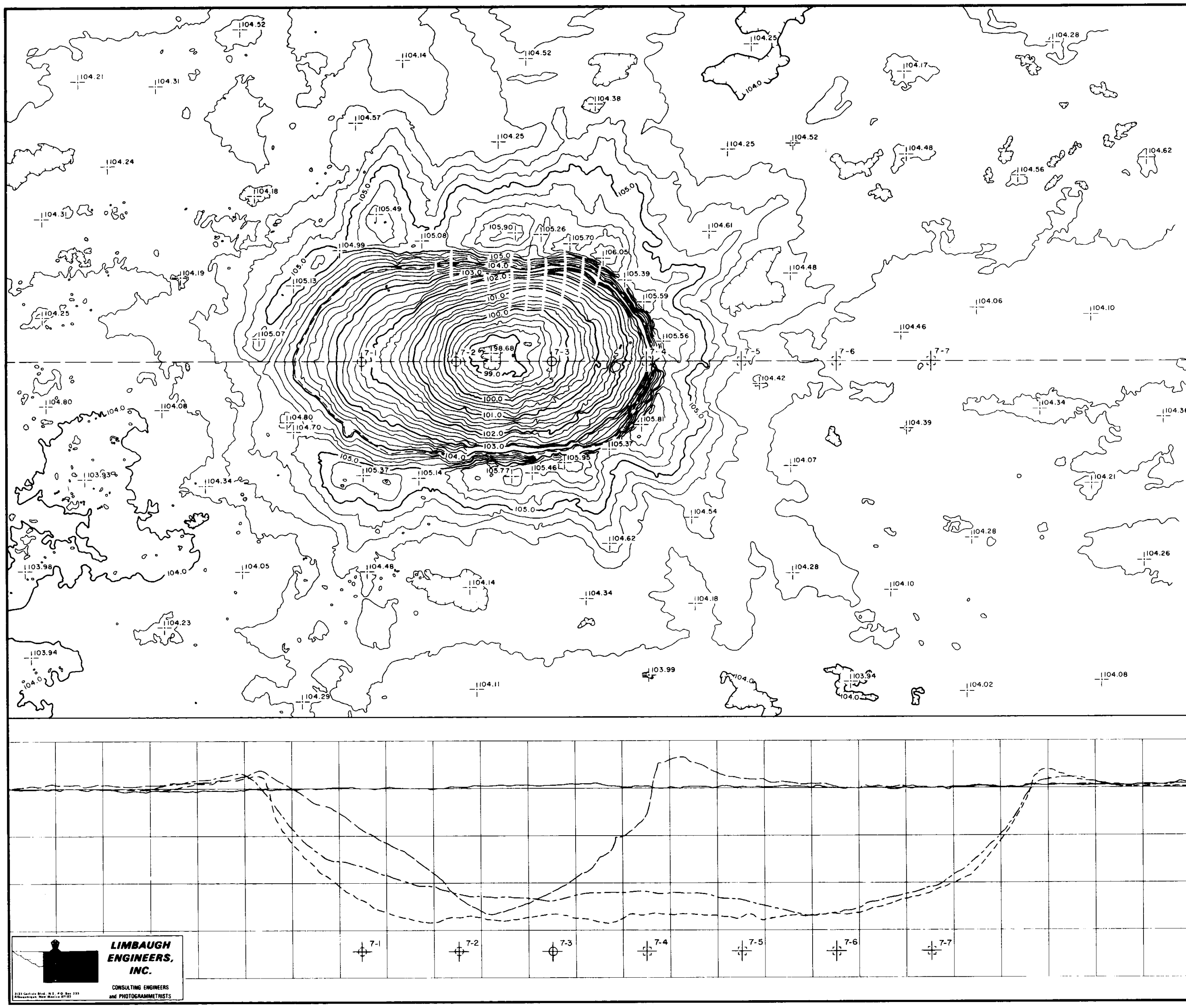
HIGHEST POINT ON LIP
2.06'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 7 1

PROFILES TAKEN OF SIMULTANEOUS DETONATION OF 7- 64 lb. CHARGES
8 ft. SPACING - 7 ft. DEEP
POST SHOT No. 2
POST SHOT No. 5

Figure 11



CRATER FORMED BY SEQUENTIAL FIRING

OF

SINGLE 64 lb. CHARGES

8 ft. SPACING - 7 ft. DEEP

POST SHOT CHARGE No.7-3

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
965.50 cu. ft.

AVERAGE CRATER DEPTH
3.98'

AVERAGE CRATER WIDTH
15.78'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 7-1	1.78'
# 7-2	4.59'
# 7-3	4.49'

DEEPEST POINT IN CRATER
5.43'

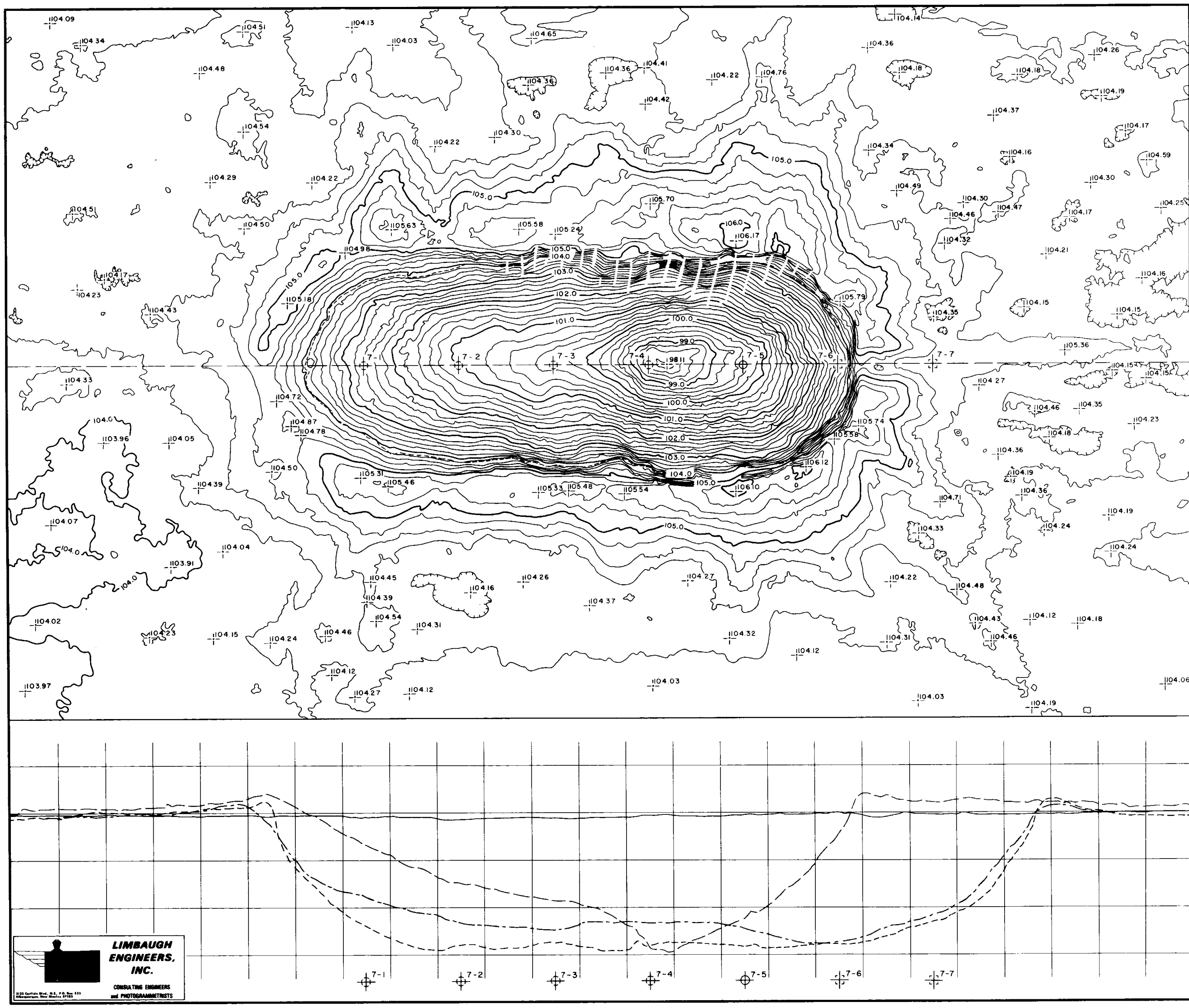
HIGHEST POINT ON LIP
1.90'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATION (PREVIOUSLY FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO 7-3

PROFILES TAKEN OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES
8 ft. SPACING - 7 ft. DEEP
POST SHOT No. 2
POST SHOT No. 5

Figure 12



CRATER FORMED BY SEQUENTIAL FIRING

OF

SINGLE 64 lb. CHARGES

8 ft. SPACING - 7 ft. DEEP

POST SHOT CHARGE No. 7-5

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
1588.66 cu. ft.

AVERAGE CRATER DEPTH
3.87'

AVERAGE CRATER WIDTH
16.72'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 7-1	1.39'
# 7-2	3.04'
# 7-3	3.85'
# 7-4	5.80'
# 7-5	4.52'

DEEPEST POINT IN CRATER
5.90'

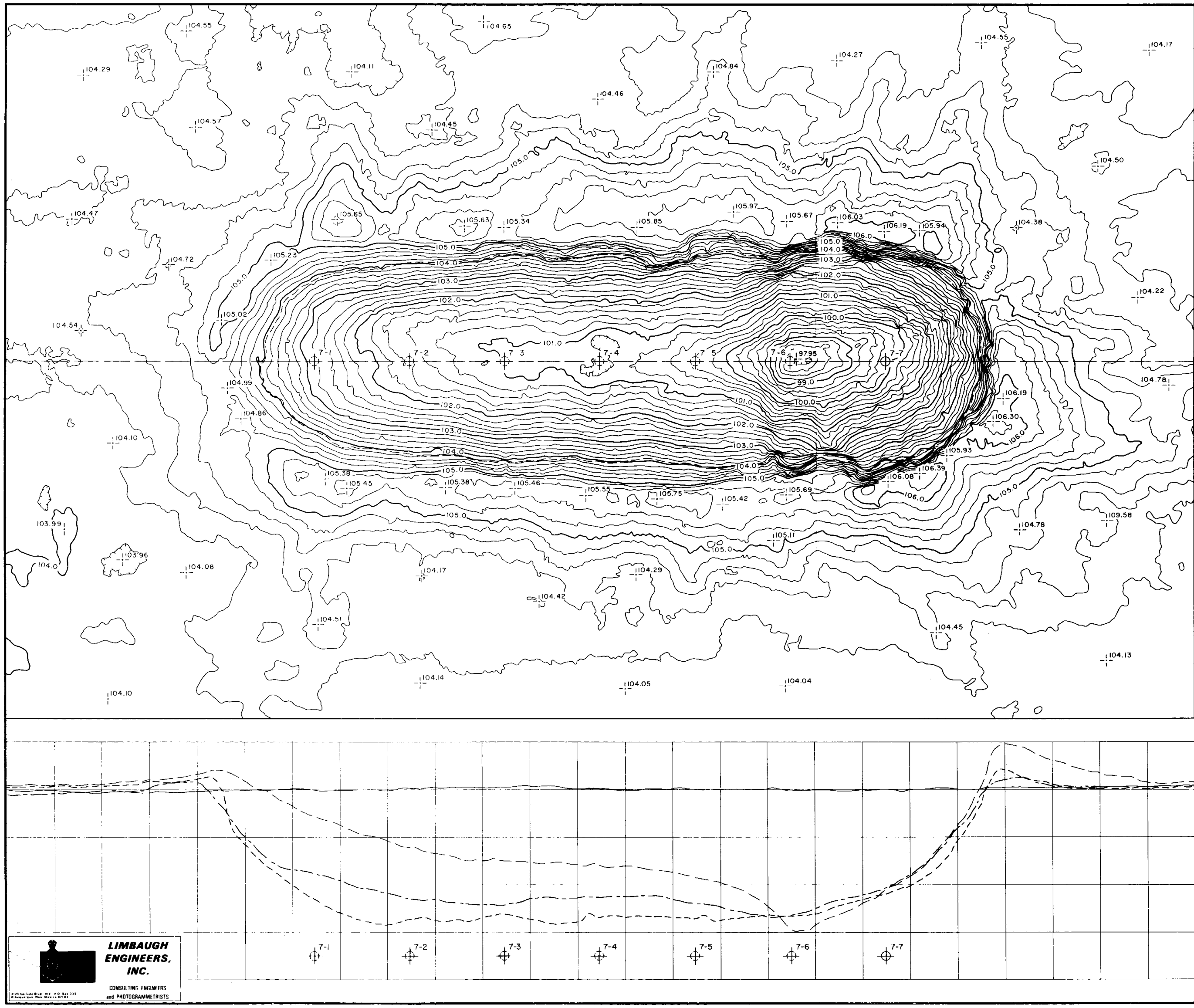
HIGHEST POINT ON LIP
2.16'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATION (PREVIOUSLY FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 7-5

PROFILES TAKEN OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES
8 ft. SPACING - 7 ft. DEEP
POST SHOT No. 2
POST SHOT No. 5

Figure 13



CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
8 ft. SPACING - 7 ft. DEEP
POST SHOT CHARGE No. 7-7

JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16
Contour Interval 0.2'

CRATER VOLUME
2088.76 cu. ft.

AVERAGE CRATER DEPTH
3.49'

AVERAGE CRATER WIDTH
16.84'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge		Charge	
# 7-1	1.14'	# 7-5	3.71'
# 7-2	2.48'	# 7-6	5.89'
# 7-3	3.15'	# 7-7	4.24'
# 7-4	3.27'		

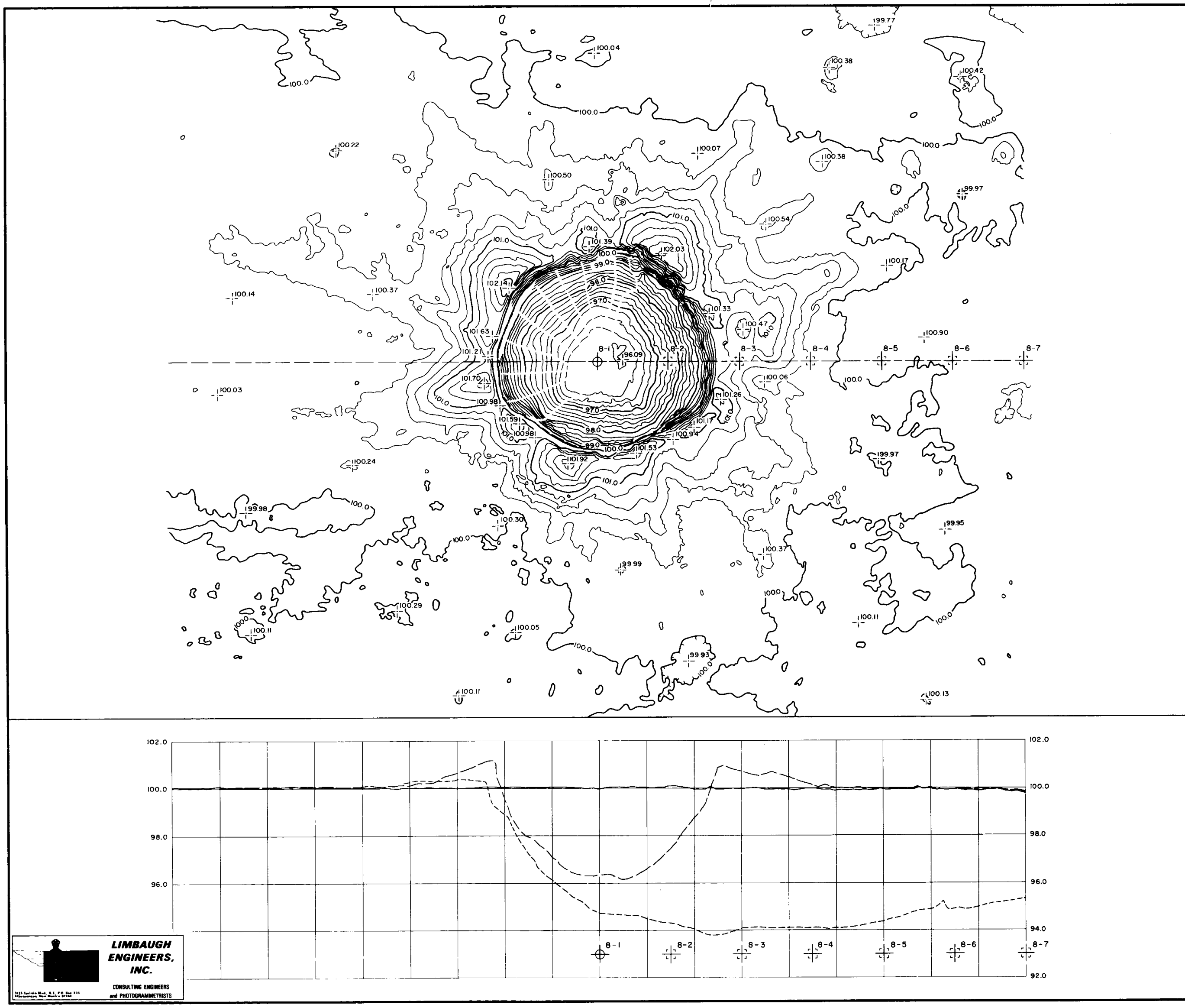
DEEPEST POINT IN CRATER
6.03'

HIGHEST POINT ON LIP
2.30'

LEGEND

CHARGE LOCATIONS (FIRED)
CHARGE LOCATIONS (PREVIOUSLY FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
CRATER PROFILE
POST SHOT NO. 7-7
PROFILES TAKEN OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 8 ft. SPACING - 7 ft. DEEP
POST SHOT No. 2
POST SHOT No. 5

Figure 14



CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES -
6 ft. SPACING - 7 ft. DEEP
POST SHOT CHARGE No. 8-1
JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
513.40 cu. ft.

RADIUS OF CIRCLE OF EQUIVALENT AREA
8.36'

DEPTHS BELOW ORIGINAL GROUND ZERO
Charge
#8-1 3.65'

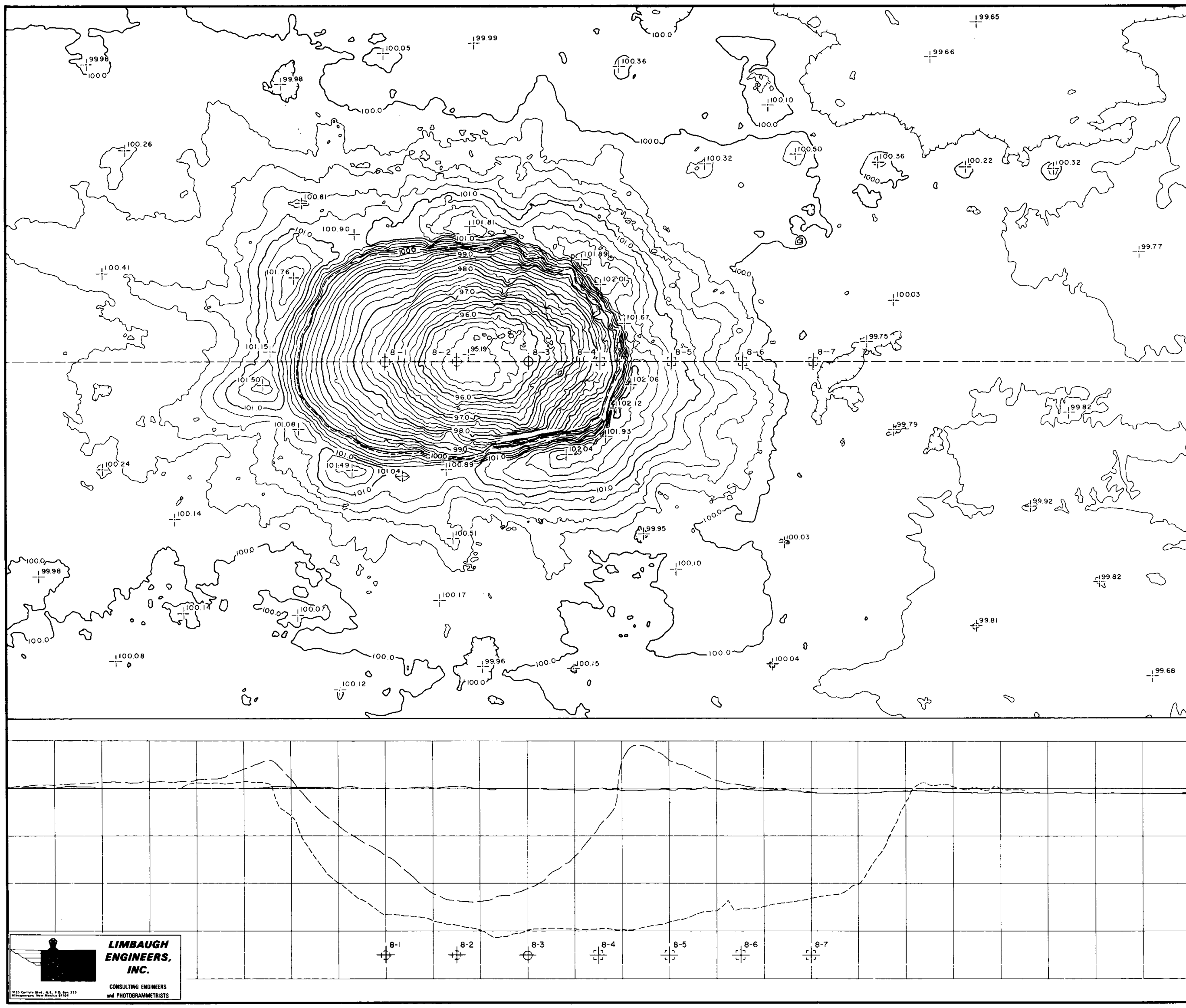
DEEPEST POINT IN CRATER
3.97'

HIGHEST POINT ON LIP
2.05'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 8-1
PROFILE TAKEN FROM POST SHOT PAD No. 11 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 7 ft. DEEP

Figure 15



CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
6 ft. SPACING - 7 ft. DEEP
POST SHOT CHARGE No. 8-3
JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
915.56 cu. ft.

AVERAGE CRATER DEPTH
4.27'

AVERAGE CRATER WIDTH
17.15'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 8-1	2.83'
# 8-2	4.81'
# 8-3	4.17'

DEEPEST POINT IN CRATER
4.88'

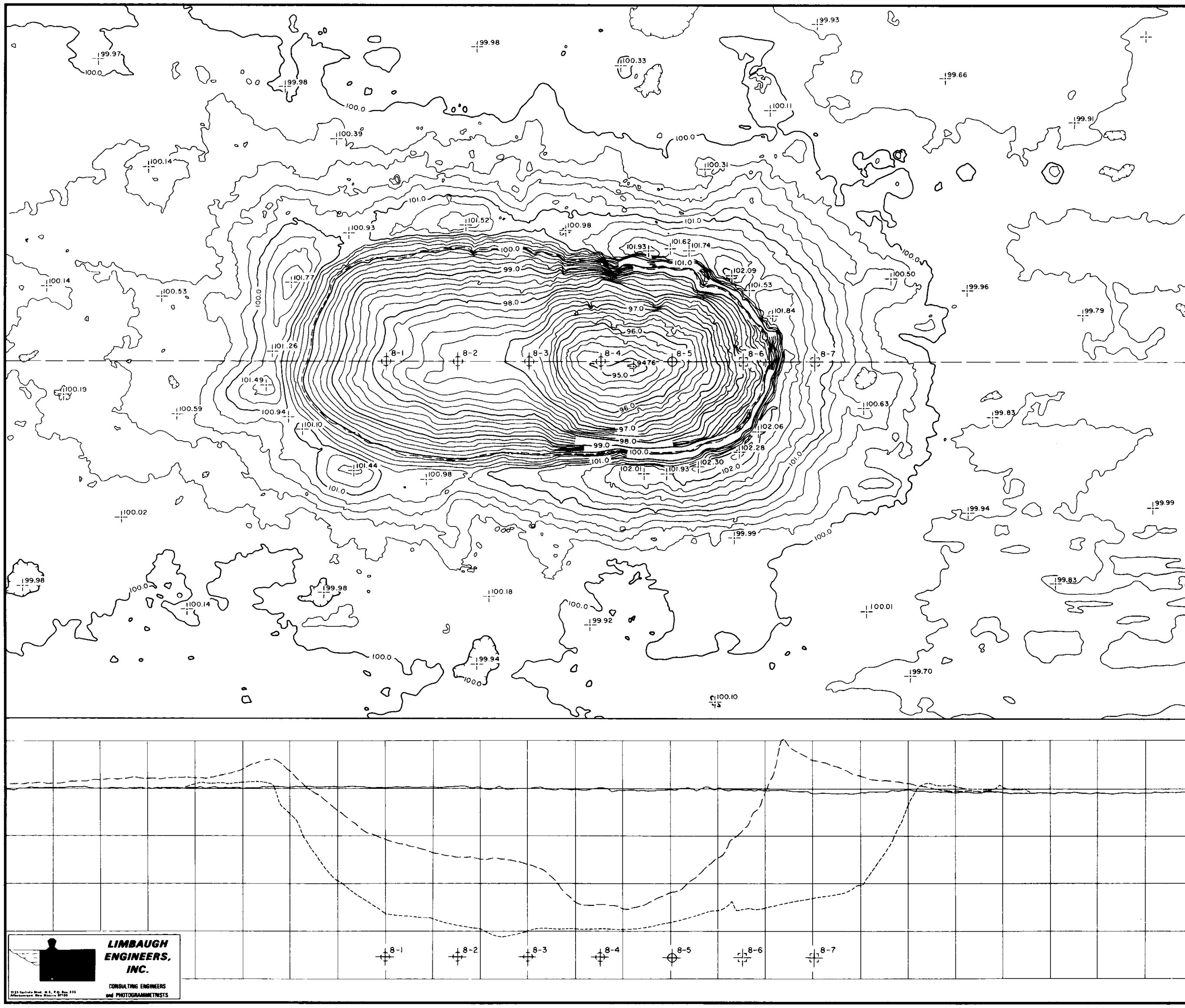
HIGHEST POINT ON LIP
2.07'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATION (PREVIOUSLY FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO

PROFILE TAKEN FROM POST SHOT PAD No. 11 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 7 ft. DEEP

Figure 16



CRATER FORMED BY SEQUENTIAL FIRING OF SINGLE 64 lb. CHARGES
6 ft. SPACING - 7 ft. DEEP
POST SHOT CHARGE No. 8-5

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
1262.26 cu. ft.

AVERAGE CRATER DEPTH
3.65'

AVERAGE CRATER WIDTH
16.65'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 8-1	2.20'
# 8-2	2.99'
# 8-3	3.20'
# 8-4	4.90'
# 8-5	4.46'

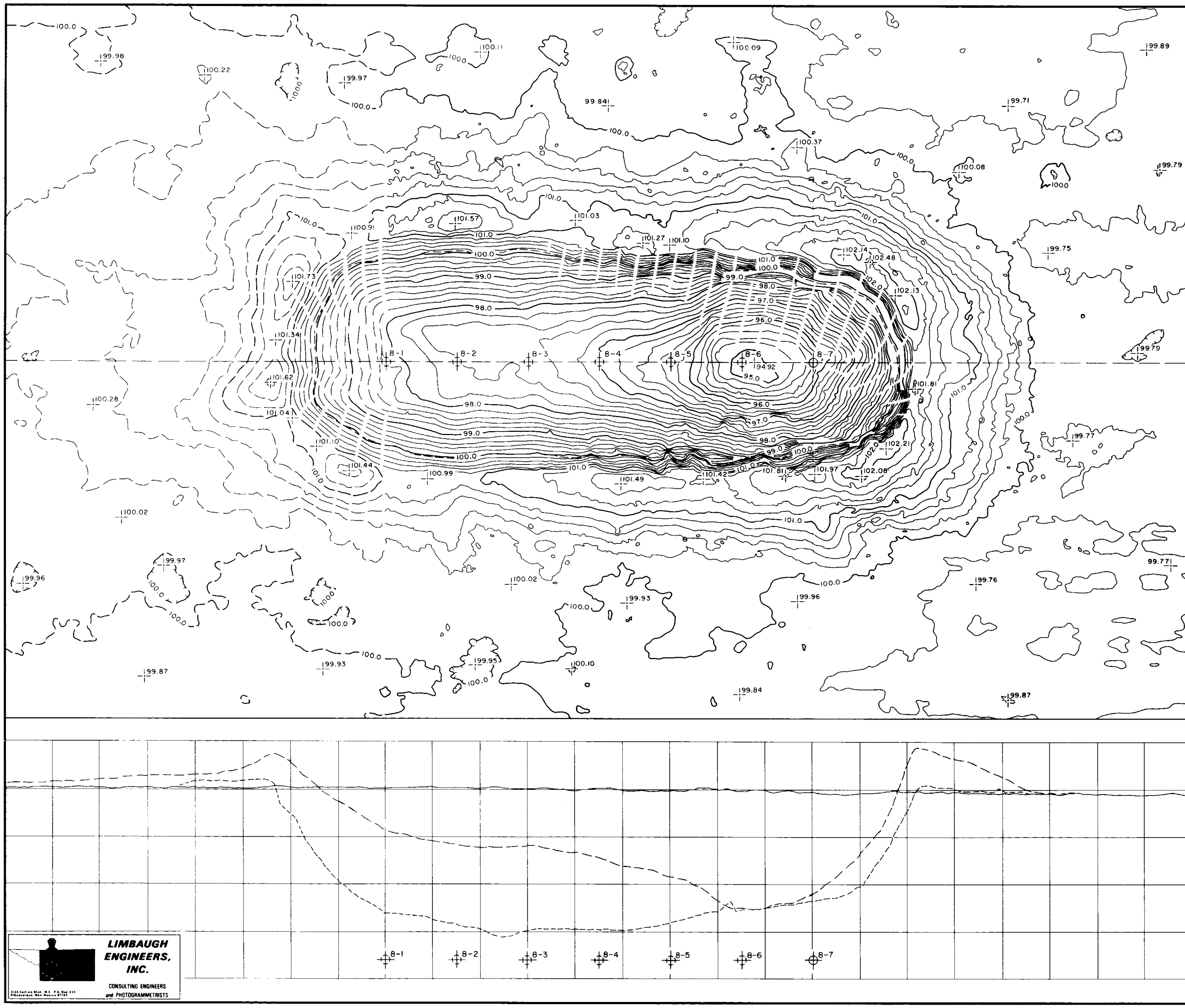
DEEPEST POINT IN CRATER
5.20'

HIGHEST POINT ON LIP
2.33'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATION (PREVIOUSLY FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 8-5
PROFILE TAKEN FROM POST SHOT PAD No. 11 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 7 ft. DEEP

Figure 17



CRATER FORMED BY SEQUENTIAL FIRING OF SINGLE 64 lb. CHARGES 6 ft. SPACING - 7 ft. DEEP POST SHOT CHARGE No. 8-7

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
1556.15 cu. ft.

AVERAGE CRATER DEPTH
3.27'

AVERAGE CRATER WIDTH
16.50'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge		Charge	
# 8-1	1.80'	# 8-5	3.69'
# 8-2	2.46'	# 8-6	4.98'
# 8-3	2.41'	# 8-7	4.24'
# 8-4	2.95'		

DEEPEST POINT IN CRATER
5.04'

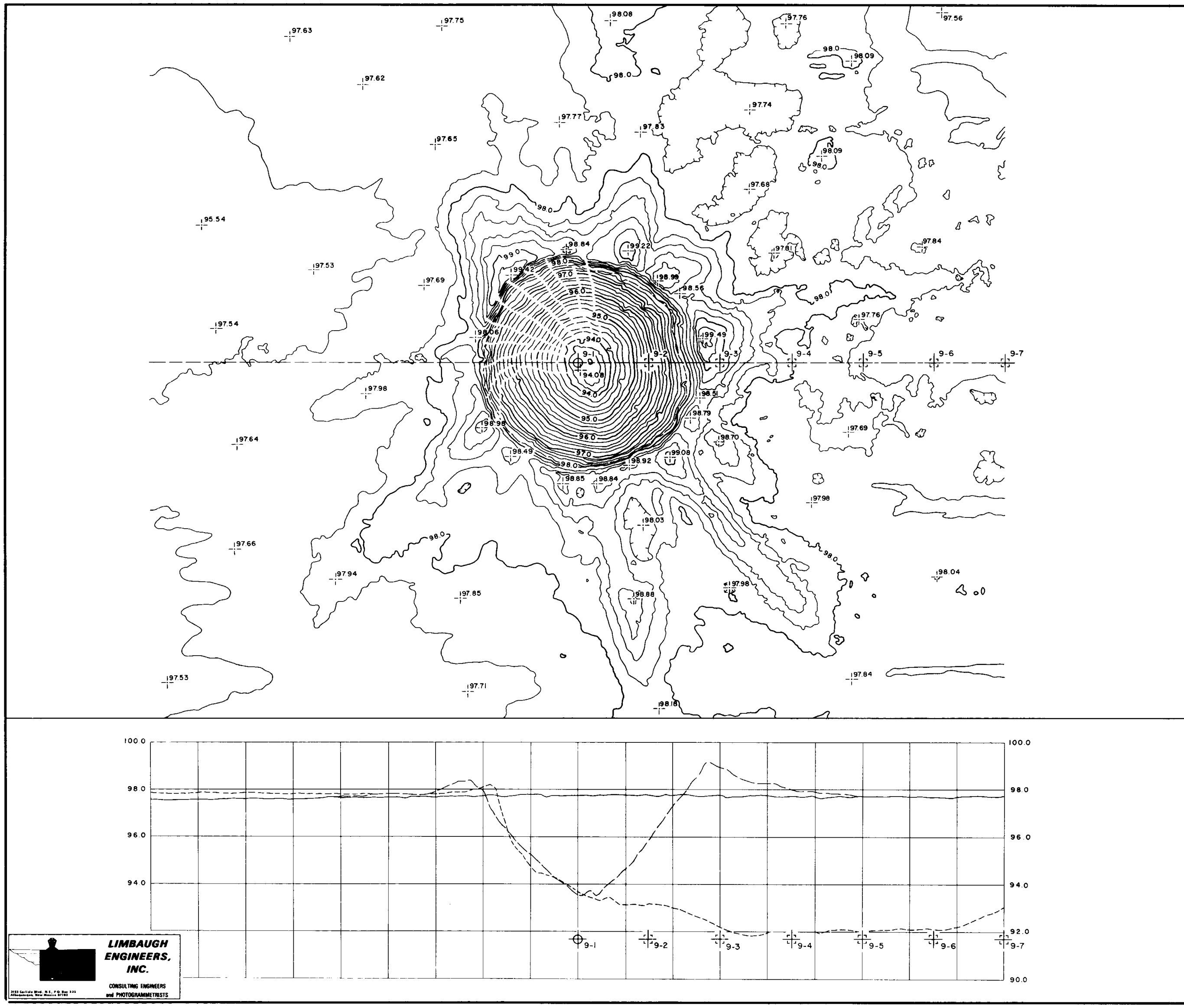
HIGHEST POINT ON LIP
2.56'

LEGEND

CHARGE LOCATIONS (FIRED)
CHARGE LOCATIONS (PREVIOUSLY FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
CRATER PROFILE
POST SHOT NO 8 7

PROFILE TAKEN FROM POST SHOT PAD No. 11 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft SPACING 7 ft. DEEP

Figure 18



CRATER FORMED BY SEQUENTIAL FIRING

OF

SINGLE 64 lb. CHARGES

6 ft. SPACING - 6 ft. DEEP

POST SHOT CHARGE No. 9-1

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
410.97 cu. ft.

RADIUS OF CIRCLE OF EQUIVALENT AREA
8.41'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 9-1	4.13'

DEEPEST POINT IN CRATER
4.25'

HIGHEST POINT ON LIP
1.82'

LEGEND

CHARGE LOCATION (FIRED)

CHARGE LOCATIONS (TO BE FIRED)

INTERCEPT

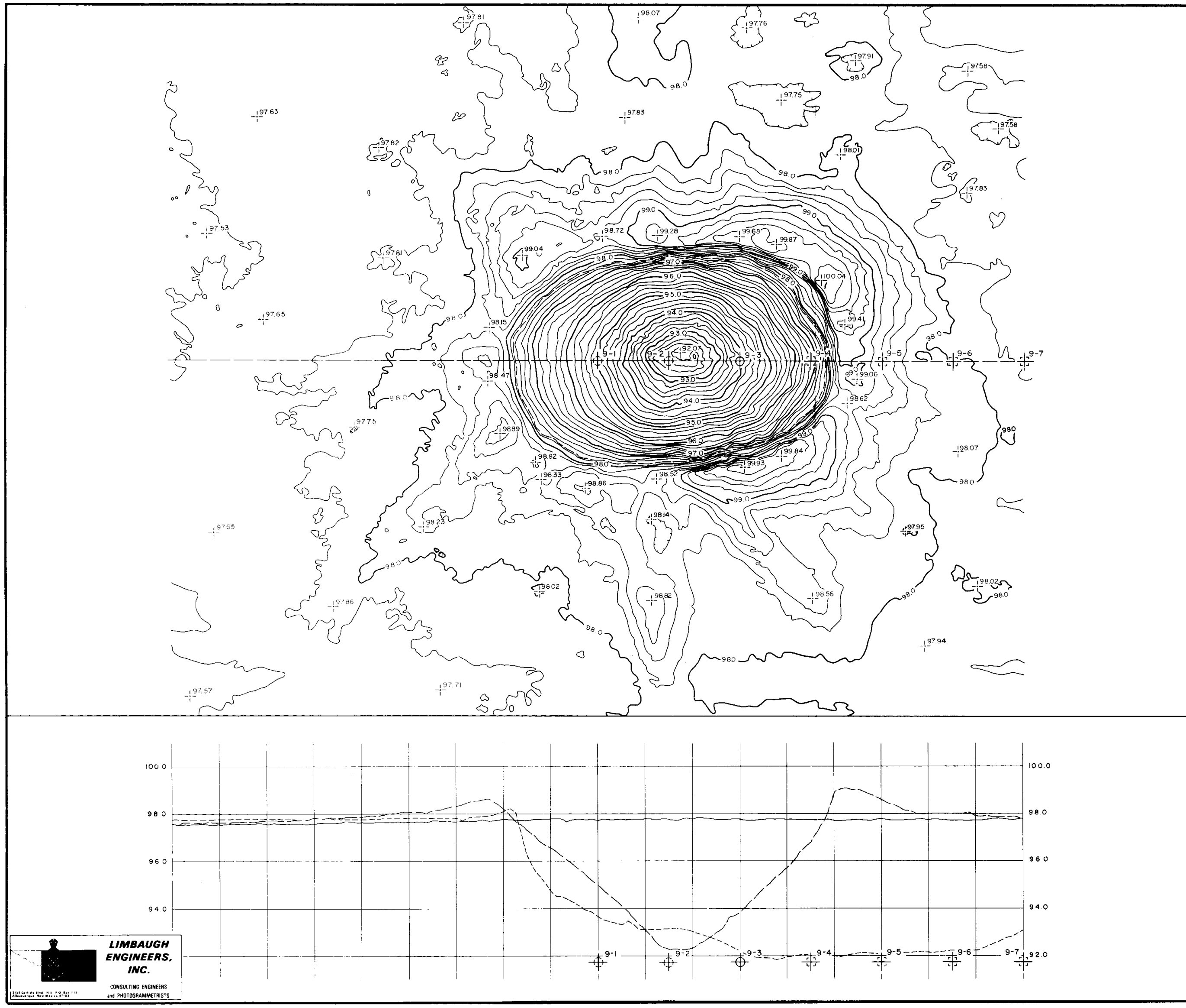
PROFILE LINE

ORIGINAL GROUND SURFACE

POST SHOT NO. 9-1

PROFILE TAKEN FROM POST SHOT PAD No. 4 OF SIMULTANEOUS DETONATION OF 7 - 64 lb. CHARGES 6 ft. SPACING - 6 ft. DEEP

Figure 19



CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
6 ft. SPACING - 6 ft. DEEP
POST SHOT CHARGE No.9-3

JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16
Contour Interval 0.2'

CRATER VOLUME
819.93 cu. ft.

AVERAGE CRATER DEPTH
4.53'

AVERAGE CRATER WIDTH
17.00'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 9-1	2.73'
# 9-2	5.49'
# 9-3	3.94'

DEEPEST POINT IN CRATER
5.65'

HIGHEST POINT ON LIP
2.33'

LEGEND

- CHARGE LOCATION (FIRED)
- CHARGE LOCATION (PREVIOUSLY FIRED)
- CHARGE LOCATIONS (TO BE FIRED)
- INTERCEPT
- PROFILE LINE
- ORIGINAL GROUND SURFACE
- POST SHOT NO. 9-3
- PROFILE TAKEN FROM POST SHOT PAD No. 4 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 6 ft. DEEP

Figure 20

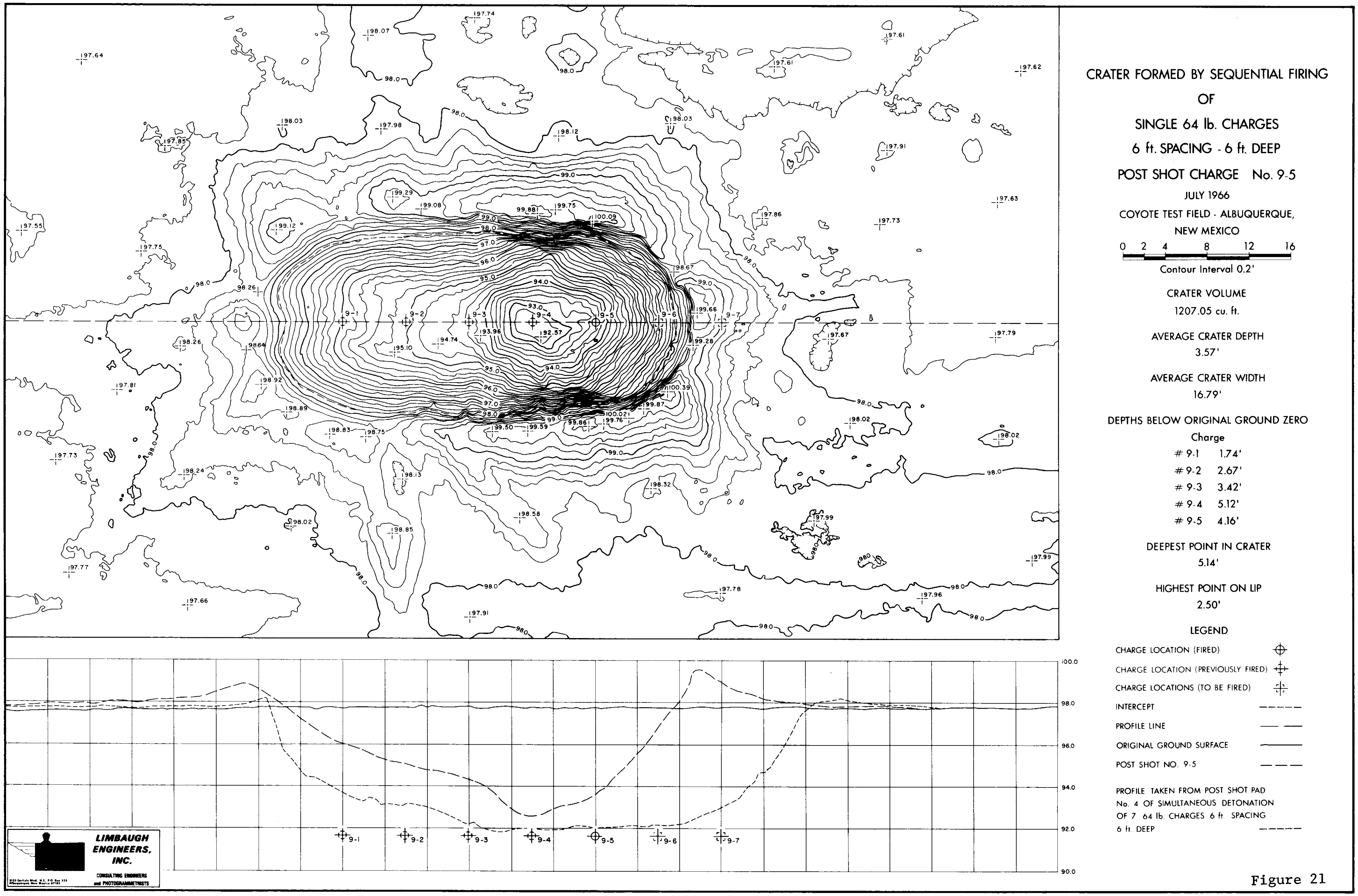
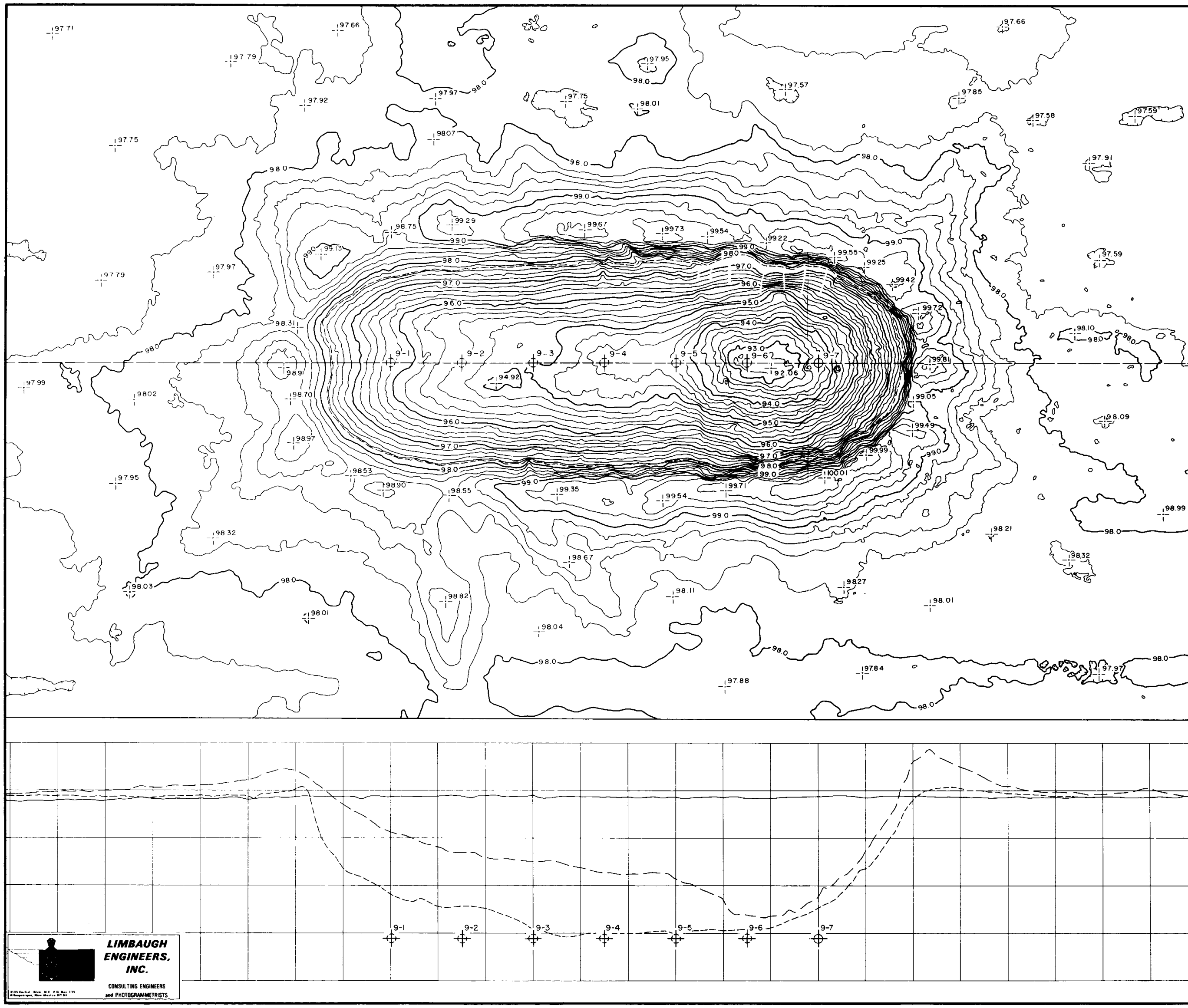

CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
6 ft. SPACING - 6 ft. DEEP
POST SHOT CHARGE No. 9-5
JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO
0 2 4 8 12 16
Contour Interval 0.2'
CRATER VOLUME
1207.05 cu. ft.
AVERAGE CRATER DEPTH
3.57'
AVERAGE CRATER WIDTH
16.79'
DEPTHS BELOW ORIGINAL GROUND ZERO
Charge
9-1 1.74'
9-2 2.67'
9-3 3.42'
9-4 5.12'
9-5 4.16'
DEEPEST POINT IN CRATER
5.14'
HIGHEST POINT ON LIP
2.50'
LEGEND
CHARGE LOCATION (FIRED)
CHARGE LOCATION (PREVIOUSLY FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 9-5
PROFILE TAKEN FROM POST SHOT PAD No. 4 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft SPACING 6 ft DEEP
9-1
9-2
9-3
9-4
9-5
9-6
9-7
100.0
98.0
96.0
94.0
92.0
90.0
LIMBAUGH ENGINEERS, INC.
CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

Figure 21



CRATER FORMED BY SEQUENTIAL FIRING OF SINGLE 64 lb. CHARGES 6 ft. SPACING - 6 ft. DEEP POST SHOT CHARGE No. 9-7

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
1522.32 cu. ft

AVERAGE CRATER DEPTH
3.28'

AVERAGE CRATER WIDTH
16.77'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge		Charge	
# 9-1	1.47'	# 9-5	3.42'
# 9-2	2.35'	# 9-6	4.95'
# 9-3	2.47'	# 9-7	4.30'
# 9-4	3.22'		

DEEPEST POINT IN CRATER
5.10'

HIGHEST POINT ON LIP
2.20'

LEGEND

CHARGE LOCATIONS (FIRED)
CHARGE LOCATIONS (PREVIOUSLY FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
CRATER PROFILE
POST SHOT NO. 9-7

PROFILE TAKEN FROM POST SHOT PAD No. 4 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 6 ft. DEEP

Figure 22

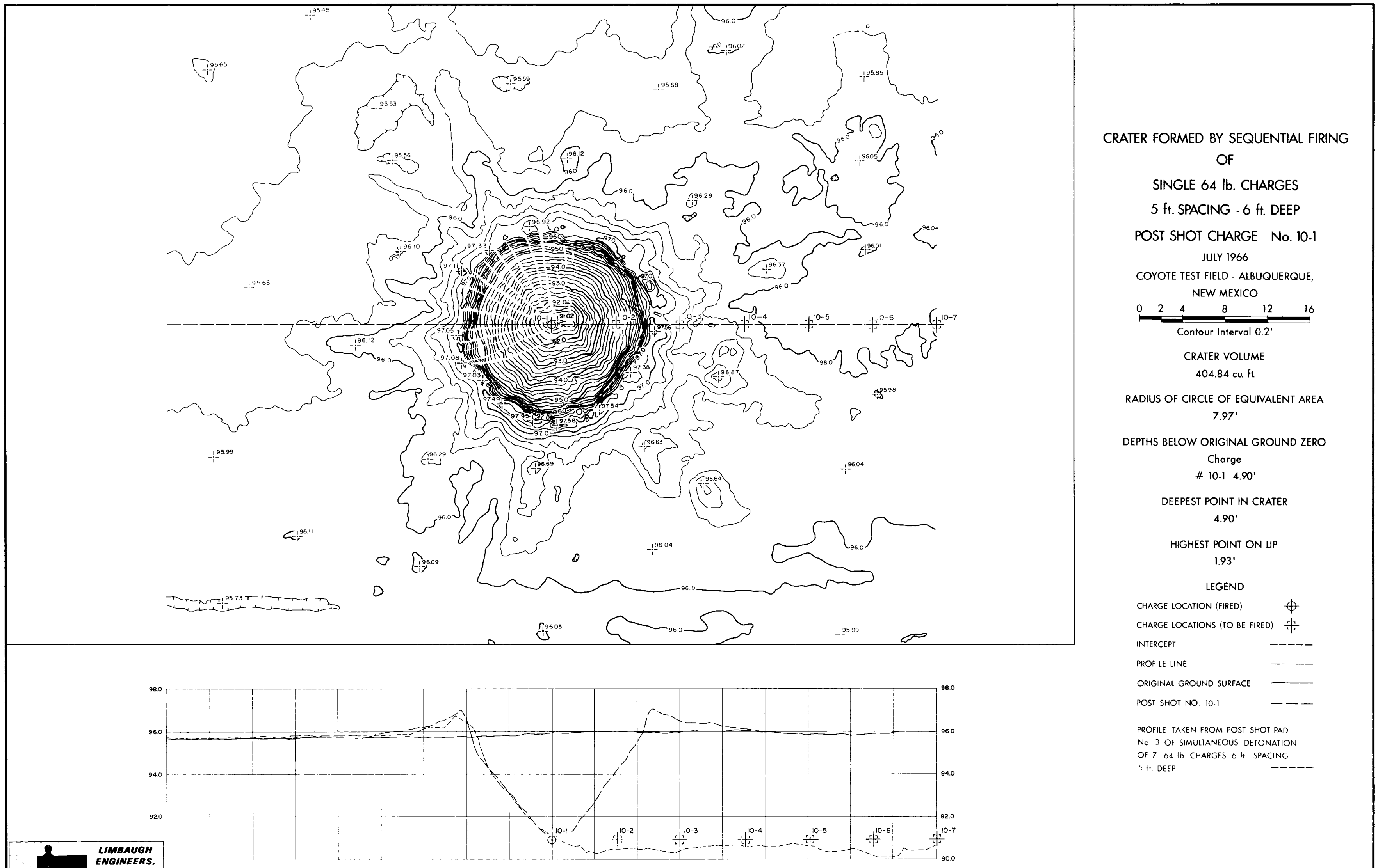
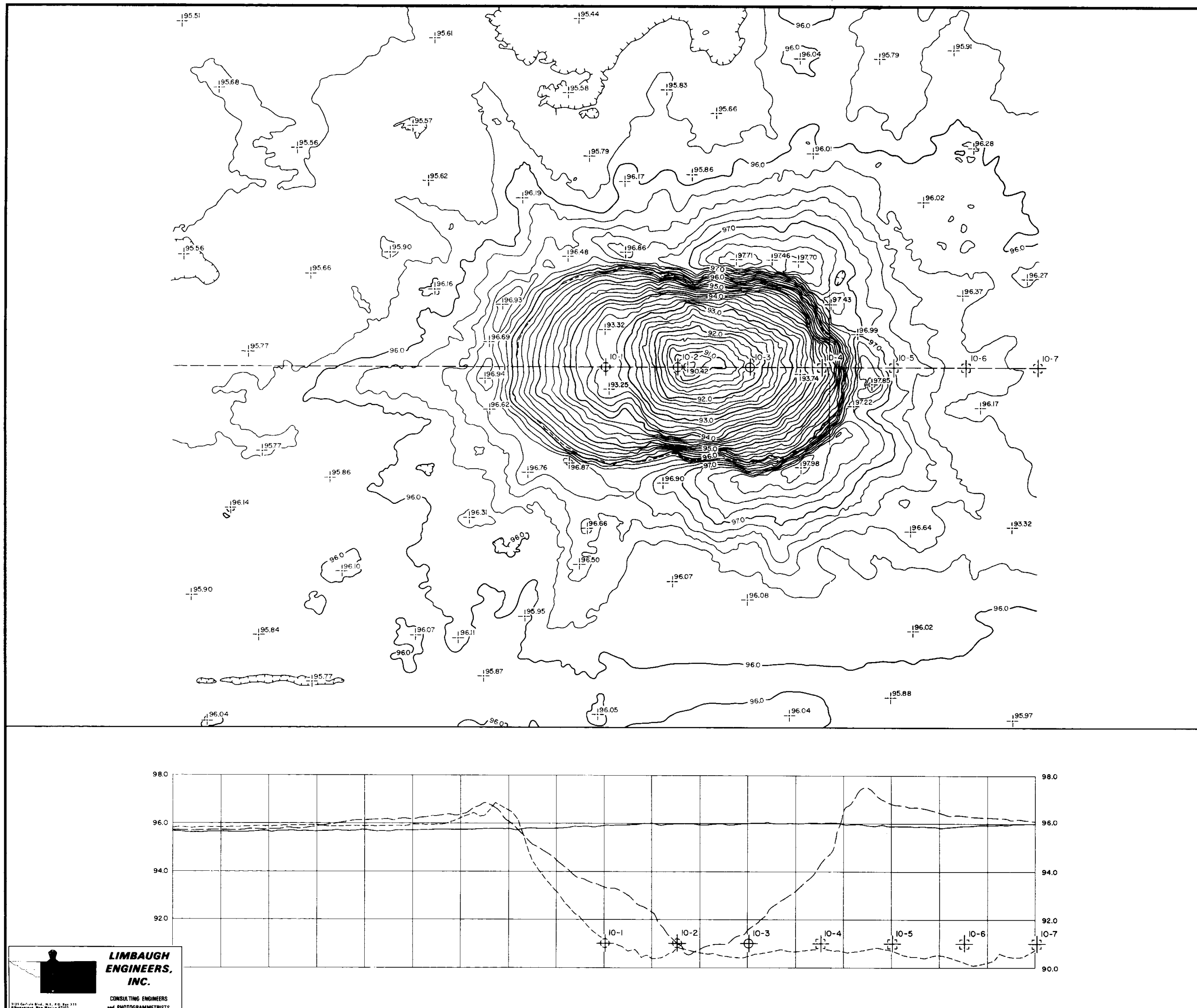

CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
5 ft. SPACING - 6 ft. DEEP
POST SHOT CHARGE No. 10-1
JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO
0 2 4 8 12 16
Contour Interval 0.2'
CRATER VOLUME
404.84 cu. ft.
RADIUS OF CIRCLE OF EQUIVALENT AREA
7.97'
DEPTHS BELOW ORIGINAL GROUND ZERO
Charge
10-1 4.90'
DEEPEST POINT IN CRATER
4.90'
HIGHEST POINT ON LIP
1.93'
LEGEND
CHARGE LOCATION (FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 10-1
PROFILE TAKEN FROM POST SHOT PAD No. 3 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 5 ft. DEEP
10-1
10-2
10-3
10-4
10-5
10-6
10-7
98.0
96.0
94.0
92.0
90.0
LIMBAUGH ENGINEERS, INC.
CONSULTING ENGINEERS and PHOTOGRAMMETRISTS

Figure 23



CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
6 ft. SPACING - 5 ft. DEEP
POST SHOT CHARGE No.10-3

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME
811.75 cu. ft.

AVERAGE CRATER DEPTH
4.24'

AVERAGE CRATER WIDTH
15.36'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 10-1	2.62'
# 10-2	5.00'
# 10-3	4.36'

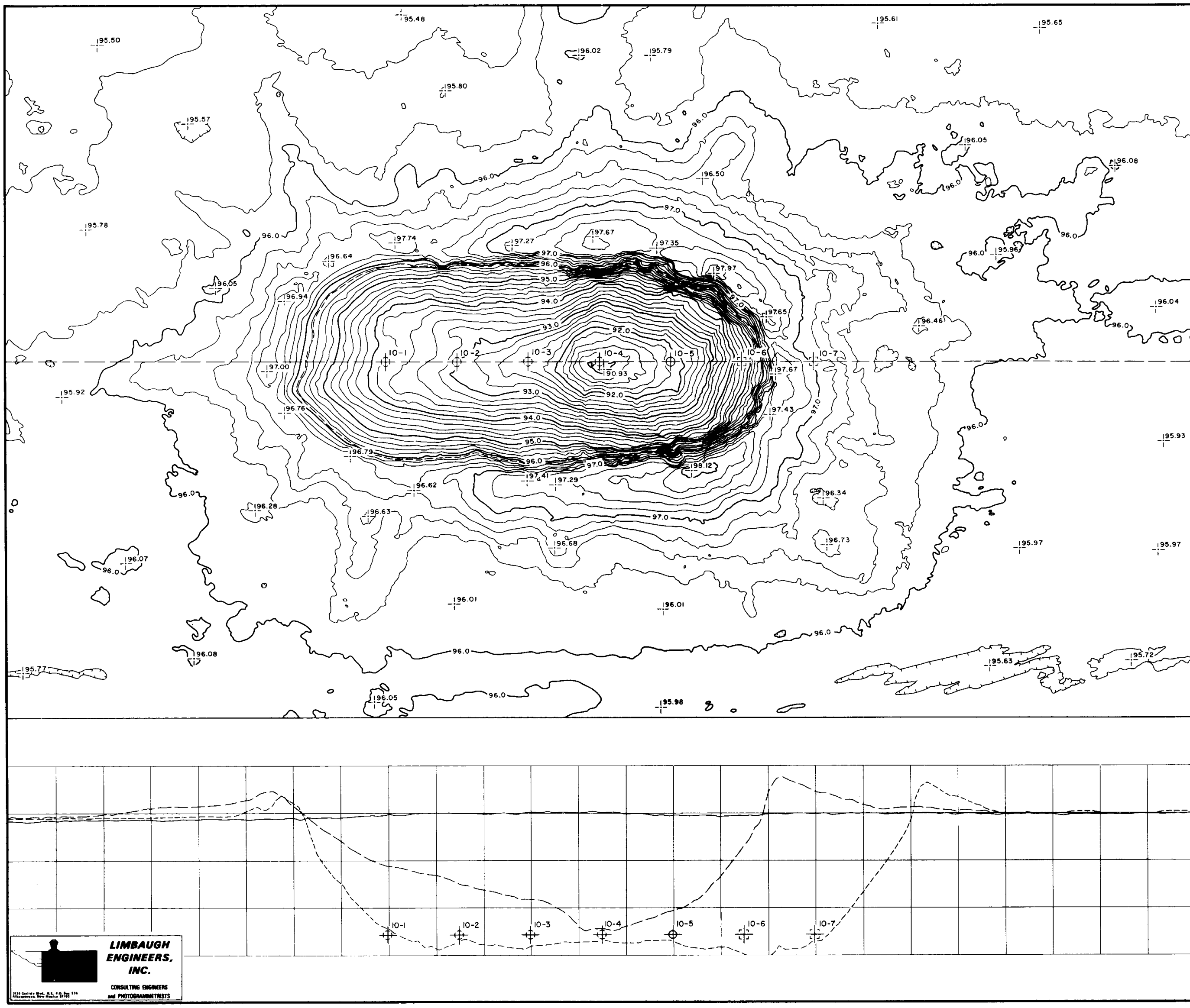
DEEPEST POINT IN CRATER
5.56'

HIGHEST POINT ON LIP
1.85'

LEGEND

CHARGE LOCATION (FIRED)
CHARGE LOCATION (PREVIOUSLY FIRED)
CHARGE LOCATIONS (TO BE FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
POST SHOT NO. 10-3
PROFILE TAKEN FROM POST SHOT PAD No. 3 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 5 ft. DEEP

Figure 24



CRATER FORMED BY SEQUENTIAL FIRING

OF

SINGLE 64 lb. CHARGES

6 ft. SPACING - 5 ft. DEEP

POST SHOT CHARGE No.10-5

JULY 1966

COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO

0 2 4 8 12 16

Contour Interval 0.2'

CRATER VOLUME

1196.82 cu. ft.

AVERAGE CRATER DEPTH

3.67'

AVERAGE CRATER WIDTH

16.20'

DEPTHS BELOW ORIGINAL GROUND ZERO

Charge	
# 10-1	2.20'
# 10-2	2.95'
# 10-3	3.65'
# 10-4	4.92'
# 10-5	4.01'

DEEPEST POINT IN CRATER

5.12'

HIGHEST POINT ON LIP

2.07'

LEGEND

CHARGE LOCATION (FIRED)

CHARGE LOCATION (PREVIOUSLY FIRED)

CHARGE LOCATIONS (TO BE FIRED)

INTERCEPT

PROFILE LINE

ORIGINAL GROUND SURFACE

POST SHOT NO. 10-5

PROFILE TAKEN FROM POST SHOT PAD No. 3 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 5 ft. DEEP

Figure 25

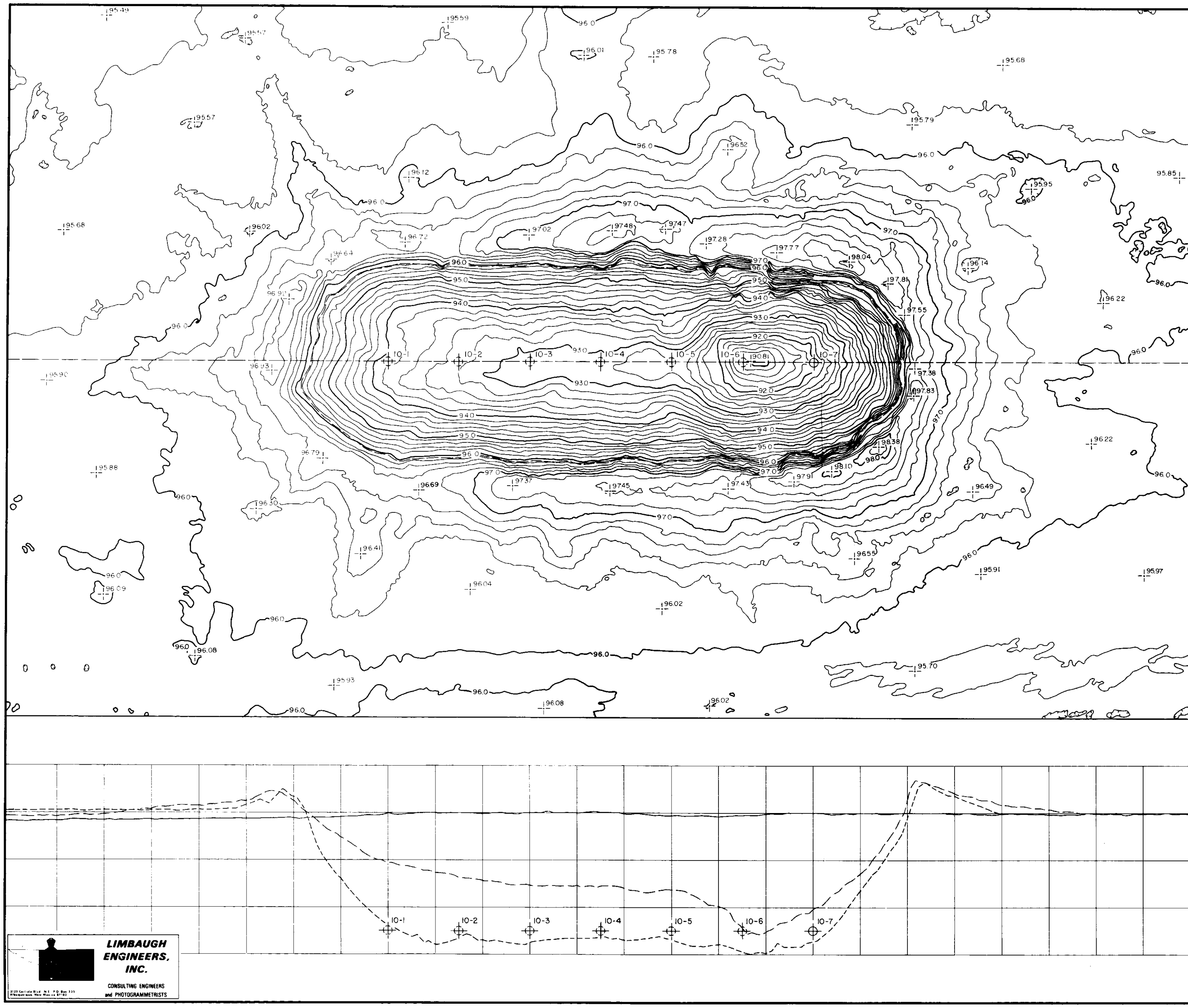

CRATER FORMED BY SEQUENTIAL FIRING
OF
SINGLE 64 lb. CHARGES
6 ft. SPACING - 5 ft. DEEP
POST SHOT CHARGE No. 10-7
JULY 1966
COYOTE TEST FIELD - ALBUQUERQUE, NEW MEXICO
0 2 4 8 12 16
Contour Interval 0.2'
CRATER VOLUME
1495.80 cu. ft.
AVERAGE CRATER DEPTH
3.34'
AVERAGE CRATER WIDTH
16.28'
DEPTHS BELOW ORIGINAL GROUND ZERO
Charge #10-1 2.07'
#10-2 2.73'
#10-3 3.05'
#10-4 3.12'
Charge #10-5 3.13'
#10-6 5.04'
#10-7 4.04'
DEEPEST POINT IN CRATER
5.10'
HIGHEST POINT ON LIP
2.29'
LEGEND
CHARGE LOCATIONS (FIRED)
CHARGE LOCATIONS (PREVIOUSLY FIRED)
INTERCEPT
PROFILE LINE
ORIGINAL GROUND SURFACE
CRATER PROFILE
POST SHOT NO 10 7
PROFILE TAKEN FROM POST SHOT PAD No. 3 OF SIMULTANEOUS DETONATION OF 7 64 lb. CHARGES 6 ft. SPACING 5 ft. DEEP
98.0
96.0
94.0
92.0
90.0
10-1
10-2
10-3
10-4
10-5
10-6
10-7
LIMBAUGH ENGINEERS, INC.
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Figure 26

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